WAVE OPTICS

INTERFERENCE OF LIGHT

NATURE OF LIGHT

Newton's corpuscular theory of light

This theory was given by Newton.

- **Characteristics of the theory**

(i) Extremely minute, very light and elastic particles are being constantly emitted by all luminous bodies (light sources) in all directions which are known as corpuscles.

(ii) These corpuscles travel with the speed of light..

(iii) When these corpuscles strike the retina of our eye then they produce the sensation of vision.

(iv) The velocity of these corpuscles in vacuum is 3×10^8 m/s.

(v) The different colours of light are due to different size of these corpuscles.

(vi) The rest mass of these corpuscles is zero.

(vii) The velocity of these corpuscles in an isotropic medium is same in all directions but it changes with the change of medium.

(viii) These corpuscles travel in straight lines.

(ix) These corpuscles are invisible.

- **The phenomena explained by this theory**

(i) Reflection and refraction of light.

(ii) Rectilinear propagation of light.

(iii) Existence of energy in light.

- **The phenomena not explained by this theory**

(i) Interference, diffraction, polarisation, double refraction and total internal reflection.

(ii) Velocity of light being greater in rarer medium than that in a denser medium.

(iii) Photoelectric effect

Huygen's Wave theory of light

This theory was enunciated by Huygen in a hypothetical medium known as luminiferrous ether.

Ether is that imaginary medium which prevails in all space and is isotropic, perfectly elastic and massless.

The velocity of light in a medium is constant but changes with change of medium.

This theory is valid for all types of waves.

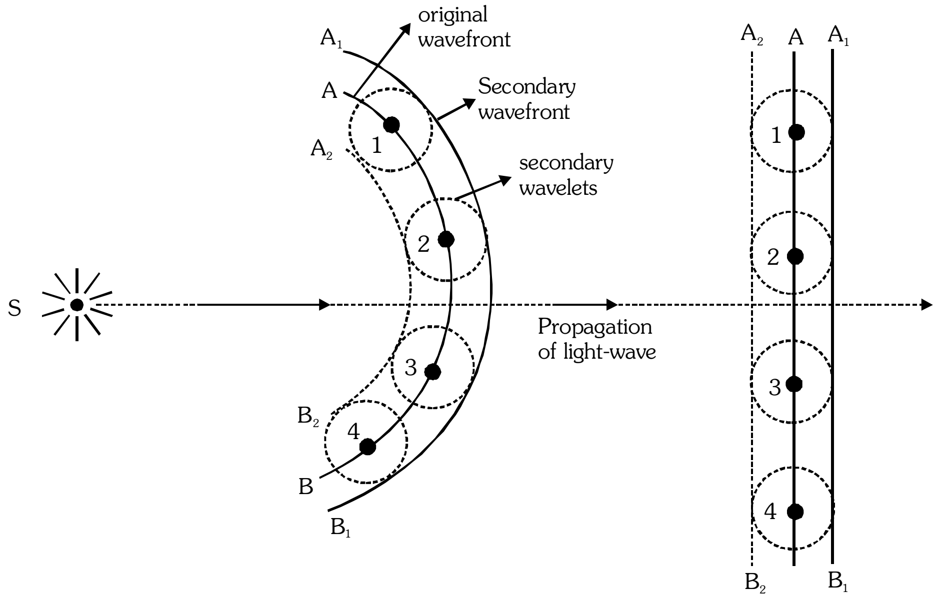
(i) The locus of all ether particles vibrating in same phase is known as wavefront.

(ii) Light travels in the medium in the form of wavefront.

(iii) When light travels in a medium then the particles of medium start vibrating and consequently a disturbance is created in the medium.

(iv) Every point on the wavefront becomes the source of secondary wavelets. It emits secondary wavelets in all directions which travel with the speed of light

(v) The tangent plane to these secondary wavelets represents the new position of wave front.



The phenomena explained by this theory

(i) Reflection, refraction, interference, diffraction.

(ii) Rectilinear propagation of light.

(iii) Velocity of light in rarer medium being greater than that in denser medium.

Phenomena not explained by this theory

(i) Photoelectric effect

WAVEFRONT, VARIOUS TYPES OF WAVEFRONT

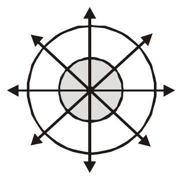
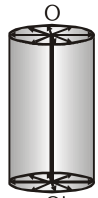
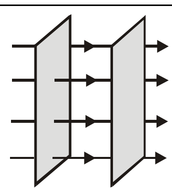
- **Wavefront**

  The locus of all the particles vibrating in the same phase is known as wavefront.

- **Types of wavefront**

  The shape of wavefront depends upon the shape of the light source from the wavefront originates. On this basis there are three types of wavefronts.

Comparative study of three types of wavefront

S.No.	Wavefront	Shape of light source	Diagram of shape of wavefront	Variation of amplitude (A) with distance	Variation of Intensity (I) with distance
1.	Spherical	Point source		$A \propto \frac{1}{d}$ or $A \propto \frac{1}{r}$	$I \propto \frac{1}{r^2}$
2.	Cylindrical	Linear source or slit		$A \propto \frac{1}{\sqrt{d}}$ or $A \propto \frac{1}{\sqrt{r}}$	$I \propto \frac{1}{r}$
3.	Plane	Extended large source or point source situated at very large distance		A = constant	I = constant

CHARACTERISTIC OF WAVEFRONT

(a) The phase difference between various particles on the wavefront is zero.

(b) These wavefronts travel with the speed of light in all directions in an isotropic medium.

(c) A point source of light always gives rise to a spherical wavefront in an isotropic medium.

(d) In anisotropic medium it travels with different velocities in different directions.

(e) Normal to the wavefront represents a ray of light.

(f) It always travels in the forward direction in the medium.

INTERFERENCE OF LIGHT

When two light waves of same frequency with constant phase difference superimpose over each other, then the resultant amplitude (or intensity) in the region of superimposition is different from the amplitude (or intensity) of individual waves.

This modification in intensity in the region of superposition is called interference.

(a) Constructive interference

When resultant intensity is greater than the sum of two individual wave intensities $[I > (I_1 + I_2)]$, then the interference is said to be constructive.

(b) Destructive interference

When the resultant intensity is less than the sum of two individual wave intensities $[I < (I_1 + I_2)]$, then the interference is said to destructive.

There is no violation of the law of conservation of energy in interference. Here, the energy from the points of minimum energy is shifted to the points of maximum energy.

TYPES OF SOURCES

- **Coherent sources**

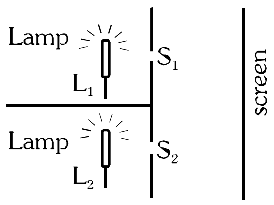
Two sources are said to be coherent if they emit light waves of the same frequency and start with same phase or have a constant phase difference. They are obtained from a single source.

Note : Laser is a source of monochromatic light waves of high degree of coherence.

- **Incoherent sources**

Two independent monochromatic sources, emit waves of same frequency.

But the waves are not in phase. So they are incoherent. This is because, atoms cannot emit light waves in same phase and these sources are said to be incoherent sources. By using two independent laser beams it has been possible to record the interference pattern.



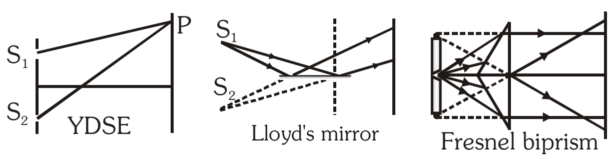
Independent Source
(non-coherent source)

METHODS OF OBTAINING COHERENT SOURCE

- **Division of wave front**

In this method, the wavefront is divided into two or more parts by reflection or refraction using mirrors, lenses or prisms.

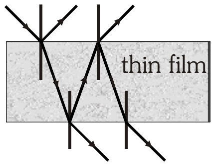
Illustration : Young's double slit experiment. Fresnel's Biprism and Lloyd's single mirror method.

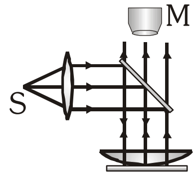


- **Division of amplitude**

The amplitude of incoming beam is divided into two or more parts by partial reflection or refraction. These divided parts travel different paths and are finally brought together to produce interference.

Illustration : The brilliant colour seen in a thin film of transparent material like soap film, oil film, Michelson's Interferro Meter, Newtons' ring etc.





Newton's rings

Condition for sustained interference

To obtain the stationary interference pattern, the following conditions must be fulfilled :

(a) The two sources should be coherent, i.e., they should vibrate in the same phase or there should be a constant phase difference between them.

(b) The two sources must emit continuous waves of same wavelength and frequency.

(c) The separation between two coherent sources should be small.

(d) The distance of the screen from the two sources should be large.

(e) For good contrast between maxima and minima, the amplitude of two interfering waves should be as nearly equal as possible and the background should be dark.

(f) For a large number of fringes in the field of view, the sources should be narrow and monochromatic.

ANALYSIS OF INTERFERENCE OF LIGHT

When two light waves having same frequency and equal or nearly equal amplitude are moving in the same direction superimpose then different points have diffeent light intensities. At some point the intensity of light is maximum and at some point it is minimum this phenomenon is known as interference of light.

Let two waves having amplitude a_1 and a_2 and same frequency, and constant phase difference ϕ superpose. Let their displacement are :

$$y_1 = a_1\sin\omega t \text{ and } y_2 = a_2\sin(\omega t + \phi)$$

$$y = y_1 + y_2 = A\sin(\omega t + \theta)$$

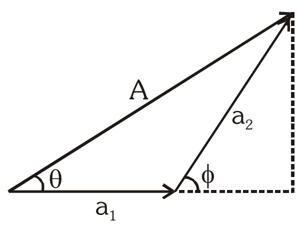
Where A = Amplitude of resultant wave

ϕ = New initial phase angle

Phasor Diagram

By right angle triangle :

$$A^2 = (a_1 + a_2\cos\phi)^2 + (a_2\sin\phi)^2$$



Resultant amplitude $A = \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi}$

Phase angle $\theta = \tan^{-1}\left(\dfrac{a_2\sin\phi}{a_1 + a_2\cos\phi}\right)$

Intensity $\propto$ (Amplitude)^2 $\Rightarrow I \propto A^2 \Rightarrow \quad I = KA^2$ so $I_1 = Ka_1^2$ & $I_2 = Ka_2^2$

$$\therefore\ I = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\phi$$

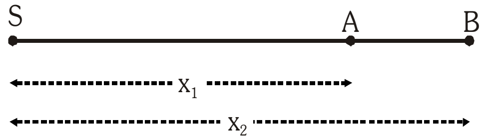
here, $2\sqrt{I_1}\sqrt{I_2}\cos\phi$ is known as interference factor.

- If the distance of a source from two points A and B is x_1 and x_2 then

Path difference $\delta = x_2 - x_1$

Phase difference $\phi = \frac{2\pi}{\lambda}(x_2 - x_1) \Rightarrow \phi = \frac{2\pi}{\lambda}\delta$

Time difference $\Delta t = \frac{\phi}{2\pi}t$



$$\frac{\text{Phase difference}}{2\pi} = \frac{\text{Path difference}}{\lambda} = \frac{\text{Time difference}}{T} \Rightarrow \frac{\phi}{2\pi} = \frac{\delta}{\lambda} = \frac{\Delta t}{T}$$

TYPES OF INTERFERENCE

Constructive Interference

When both waves are in same phase then phase difference is an even multiple of $\pi \Rightarrow \phi = 2n\pi$; $n = 0,1,2 \ldots$

- Path difference is an even multiple of $\frac{\lambda}{2}$

$$\because \frac{\phi}{2\pi} = \frac{\delta}{\lambda} \Rightarrow \frac{2n\pi}{2\pi} = \frac{\delta}{\lambda} \Rightarrow \delta = 2n\left(\frac{\lambda}{2}\right) \Rightarrow \delta = n\lambda \text{ (where } n = 0,1,2\ldots)$$

- When time difference is an even multiple of $\frac{T}{2}$ $\quad \therefore \Delta t = 2n\left(\frac{T}{2}\right)$
- In this condition the resultant amplitude and intensity will be maximum.

$$A_{max} = (a_1 + a_2) \Rightarrow I_{max} = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2} = (\sqrt{I_1} + \sqrt{I_2})^2$$

Destructive Interference

When both the waves are in opposite phase. So phase difference is an odd multiple of π.

$\phi = (2n-1)\pi$; $n = 1, 2 \ldots$

- When path difference is an odd multiple of $\frac{\lambda}{2}$, $\delta = (2n-1)\frac{\lambda}{2}$, $n = 1, 2 \ldots$
- When time difference is an odd multiple of $\frac{T}{2}$, $\Delta t = (2n-1)\frac{T}{2}$, $(n=1,2\ldots)$

In this condition the resultant amplitude and intensity of wave will be minimum.

$$A_{min} = (a_1 - a_2) \Rightarrow I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2$$

GOLDEN KEY POINTS

- Interference follows law of conservation of energy.
- Average Intensity $I_{av} = \frac{I_{max} + I_{min}}{2} = I_1 + I_2 = a_1^2 + a_2^2$
- Intensity $\propto$ width of slit $\propto$ (amplitude)$^2 \Rightarrow I \propto w \propto a^2 \Rightarrow \frac{I_1}{I_2} = \frac{w_1}{w_2} = \frac{a_1^2}{a_2^2}$
- $\frac{I_{max}}{I_{min}} = \left[\frac{\sqrt{I_1} + \sqrt{I_2}}{\sqrt{I_1} - \sqrt{I_2}}\right]^2 = \left[\frac{a_1 + a_2}{a_1 - a_2}\right]^2 = \left[\frac{a_{max}}{a_{min}}\right]^2$
- Fringe visibility $V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \times 100\%$ when $I_{min} = 0$ then fringe visibility is maximum

i.e. when both slits are of equal width the fringe visibility is the best and equal to 100%.

Illustrations

Illustration 1

If two waves represented by $y_1 = 4 \sin\omega t$ and $y_2 = 3 \sin(\omega t + \frac{\pi}{3})$ interfere at a point. Find out the amplitude of the resulting wave.

Solution

Resultant amplitude A $= \sqrt{a_1^2 + a_2^2 + 2a_1a_2\cos\phi} = \sqrt{(4)^2 + (3)^2 + 2.(4)(3)\cos\frac{\pi}{3}} \Rightarrow A \simeq 6$

Illustration 2

Two beams of light having intensities I and 4I interferer to produce a fringe pattern on a screen. The phase difference between the beam is $\frac{\pi}{2}$ at point A and 2π at point B. Then find out the difference between the resultant intensities at A and B.

Solution

Resultant intensity $I = I_1 + I_2 + 2\sqrt{I_1}\sqrt{I_2}\cos\phi$

Resultant intensity at point A is $I_A = I + 4I + 2\sqrt{I}\sqrt{4I}\cos\frac{\pi}{2} = 5I$

Resultant intensity at point B, $I_B = I + 4I + 2\sqrt{I}\sqrt{4I}\cos 2\pi = 9I$ ($\because \cos 2\pi = 1$) $\therefore I_B - I_A = 9I - 5I \Rightarrow 4I$

Illustration 3

In an interference pattern, the slit widths are in the ratio 1:9. Then find out the ratio of minimum and maximum intensity.

Solution

Slit width ratio

$$\frac{w_1}{w_2} = \frac{1}{9} \because \frac{I_1}{I_2} = \frac{w_1}{w_2} = \frac{a_1^2}{a_2^2} = \frac{1}{9} \Rightarrow \frac{a_1}{a_2} = \frac{1}{3} \Rightarrow 3a_1 = a_2 \therefore \frac{I_{min}}{I_{max}} = \frac{(a_1 - a_2)^2}{(a_1 + a_2)^2} = \frac{(a_1 - 3a_1)^2}{(a_1 + 3a_1)^2} = \frac{4}{16} = 1:4$$

Illustration 4

The intensity variation in the interference pattern obtained with the help of two coherent sources is 5% of the average intensity. Find out the ratio of intensities of two sources.

Solution

Let I_{avg} = 100 units

$$\frac{I_{max}}{I_{min}} = \frac{105}{95} = \frac{21}{19} \Rightarrow \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{21}{19} \Rightarrow \frac{a_1 + a_2}{a_1 - a_2} = \sqrt{\frac{21}{19}} = 1.05 \Rightarrow a_1 + a_2 = 1.05\,a_1 - 1.05\,a_2$$

$$0.05\,a_1 = 2.05\,a_2 \Rightarrow \frac{a_1}{a_2} = \frac{2.05}{0.05} = \frac{41}{1} \therefore \frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} = \frac{1680}{1}$$

Illustration 5

Can two different bulbs, similar in all respect act as coherent sources ? Give reasons for your answer.

Solution.

No, because the light waves emitted by two independent bulbs will not have stable constant phase difference.

BEGINNER'S BOX-1

1. Consider interference between two sources of intensities I and 4I. Obtain intensity at a point where phase difference is $\frac{\pi}{2}$.

2. Two coherent sources whose intensity ratio is 81 : 1 produce interference fringes. Calculate the ratio of intensity of maxima and minima in the fringe system.

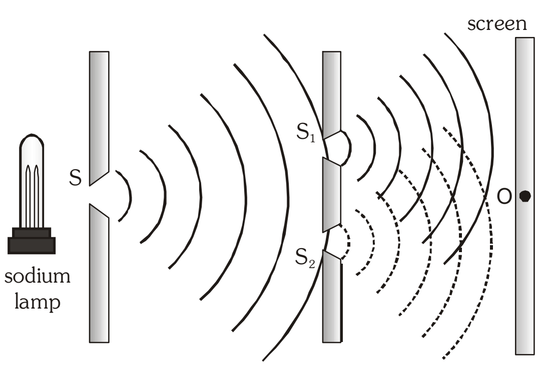
3. Consider interference between two sources of intensity I and 4I. Find the resultant intensity. where phase difference is

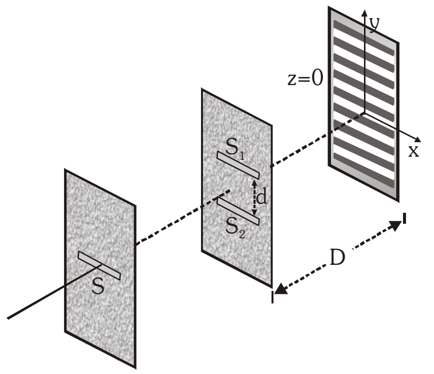
(a) $\frac{\pi}{4}$ (b) π (c) 4π

YOUNG'S DOUBLE SLIT EXPERIMENT (YDSE)

According to Huygen, light is a wave. It is proved experimentally by YDSE.

S is a narrow slit illuminated by a monochromatic source of light sends wave fronts in all directions. Slits S_1 and S_2 become the source of secondary wavelets which are in phase and of same frequency. These waves are superimposed on each other which give rise to interference. Alternate dark and bright bands are obtained on a screen (called interference fringes) placed certain distance from the plane of slit S_1 and S_2. Central fringe is always bright (due to path length S_1O and S_2O to centre of screen are equal) and is called central maxima.





- In YDSE division of wavefront takes place.
- If one of the two slit is closed, the interference pattern disappears. It shows that two coherent sources are required to produce interference pattern.
- If white light is used as parent source, then the fringes will be coloured and of unequal width.

(i) Central fringe will be white.

(ii) The fringe closest on either side of the central white fringe is red and the farthest will appear blue. After a few fringes, no clear fringe pattern is seen.

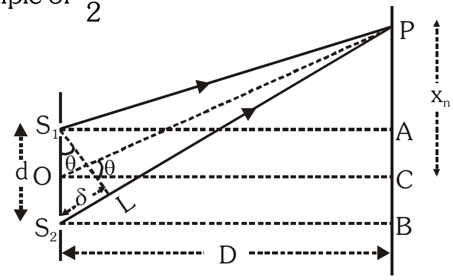
CONDITION FOR BRIGHT AND DARK FRINGES

Bright Fringe

D = distance between slit and screen, d = distance between slit S_1 and S_2

Bright fringe occurs due to constructive interference.

$\because$ For constructive interference path difference should be even multiple of $\frac{\lambda}{2}$



$\therefore$ Path difference $\delta = PS_2 - PS_1 = S_2L = (2n)\frac{\lambda}{2}$

In ΔPCO $\tan\theta = \frac{x_n}{D}$; In ΔS_1S_2L $\sin\theta = \frac{\delta}{d}$

$\delta = n\lambda$ for bright fringes

If θ is small then $\tan\theta \simeq \sin\theta \Rightarrow \frac{x_n}{D} = \frac{\delta}{d}$

The distance of n^{th} bright fringe from the central bright fringe $x_n = n\frac{D\lambda}{d}$

Dark Fringe

Dark fringe occurs due to destructive interference.

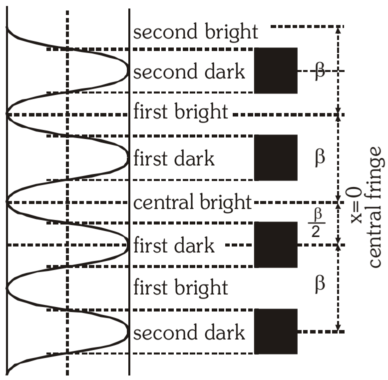
$\because$ For destructive interference path difference should be odd multiple of $\frac{\lambda}{2}$.

$\therefore$ Path difference $\delta = (2m-1)\frac{\lambda}{2}$

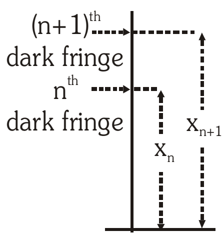
The distance of the m^{th} dark fringe from the central bright fringe $x_m = \frac{(2m-1)D\lambda}{2d}$

FRINGE WIDTH

The distance between two successive bright or dark fringe is known as fringe width.

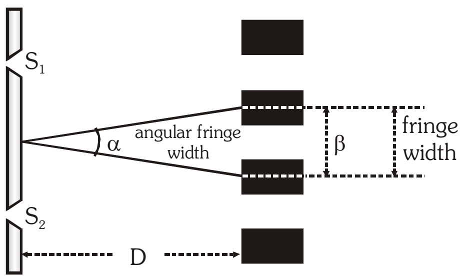


$$\beta = x_{n+1} - x_n = \frac{(n+1)D\lambda}{d} - \frac{nD\lambda}{d}$$



Fringe Width $\beta = \frac{D\lambda}{d}$

ANGULAR FRINGE WIDTH



Angular fringe width $\alpha = \frac{\beta}{D}$, $\alpha = \frac{\lambda}{d}$ $\left[\because \frac{\beta}{D} = \frac{\lambda}{d}\right]$

- The distance of n^{th} bright fringe from the central bright fringe $x_n = \frac{n\lambda D}{d} = n\beta$

- The distance between n_1 and n_2 bright fringe $x_{n_2} - x_{n_1} = n_2\frac{\lambda D}{d} - n_1\frac{\lambda D}{d} = (n_2 - n_1)\beta$

- The distance of m^{th} dark fringe from central fringe $x_m = \frac{(2m-1)D\lambda}{2d} = \frac{(2m-1)\beta}{2}$

- The distance of n^{th} bright fringe from m^{th} dark fringe $x_n - x_m = n\frac{D\lambda}{d} - \frac{(2m-1)D\lambda}{2d} = n\beta - \frac{(2m-1)\beta}{2}$

$$x_n - x_m = \left[n - \frac{(2m-1)}{2}\right]\beta$$

GOLDEN KEY POINTS

- If the whole apparatus is immersed in a liquid of refractive index μ, then wavelength of light

  $\lambda' = \frac{\lambda}{\mu}$ since $\mu > 1$ so $\lambda' < \lambda$ $\Rightarrow$ wavelength will decrease. Hence fringe width ($\beta \propto \lambda$) will decrease

  $\Rightarrow$ fringe width in liquid $\beta' = \beta/\mu$. Angular width will also decrease.
- With increase in distance between slit and screen D, angular width of maxima does not change, fringe width β increases linearly with D but the intensity of fringes decreases.
- If an additional phase difference of π is created in one of the wave then the central fringe becomes dark.
- When wavelength λ_1 is used to obtain a fringe n_1. At the same point wavelength λ_2 is required to obtain a fringe n_2 then $n_1\lambda_1 = n_2\lambda_2$
- When waves from two coherent sources S_1 and S_2 interfere in space the shape of the fringe is hyperbolic with foci at S_1 and S_2.

Illustrations

Illustration 6

Laser light of wavelength 630 nm incident on a pair of slits produces an interference pattern in which the fringes are separated by 8.1 mm. A second laser light produces an interference pattern in which the fringes are separated by 7.2 mm. Calculate the wavelength of the second light.

Solution

Fringe separation is given by $\beta = \frac{\lambda D}{d}$ i.e. $\frac{\beta_2}{\beta_1} = \frac{\lambda_2}{\lambda_1} \Rightarrow \lambda_2 = \frac{\beta_2}{\beta_1} \times \lambda_1 = \frac{7.2}{8.1} \times 630 = 560$ nm

Illustration 7

A double slit is illuminated by light of wavelength 6000 Å. The slits are 0.1 cm apart and the screen is placed one metre away. Calculate :

(i) The angular position of the 10^{th} maximum in radians and

(ii) separation between the two adjacent minima.

Solution

(i) $\lambda = 6000$ Å $= 6 \times 10^{-7}$ m, d = 0.1 cm = 1×10^{-3}m, D = 1m, n = 10

Angular position $\theta_n = \frac{n\lambda}{d} = \frac{10 \times 6 \times 10^{-7}}{10^{-3}} = 6 \times 10^{-3}$ rad.

(ii) Separation between two adjacent minima = fringe width β

$$\beta = \frac{\lambda D}{d} = \frac{6 \times 10^{-7} \times 1}{1 \times 10^{-3}} = 6 \times 10^{-4}\text{m} = 0.6 \text{ mm}$$

Illustration 8

In Young's double slit experiment the fringes are formed at a distance of 1m from double slits of separation 0.12 mm. Calculate

(i) The distance of 3rd dark band from the centre of the screen.

(ii) The distance of 3rd bright band from the centre of the screen, given $\lambda = 6000$Å

Solution

(i) For m^{th} dark fringe $x'_m = (2m-1)\frac{D\lambda}{2d}$ given, D = 1m = 100 cm, d = 0.12 mm = 0.012 cm

$$x'_m = \frac{(2 \times 3 - 1) \times 100 \times 6 \times 10^{-5}}{2 \times 0.012} = 1.25 \text{ cm} \quad [\because m = 3 \text{ and } \lambda = 6 \times 10^{-5} \text{ cm}]$$

(ii) For n^{th} bright fringe $x_n = \frac{nD\lambda}{d} \Rightarrow x_n = \frac{3 \times 100 \times 6 \times 10^{-5}}{0.012} = 1.5$ cm $\quad [\because n = 3]$

Illustration 9

In Young's double slit experiment the two slits are illuminated by light of wavelength 5890Å and the distance between the fringes obtained on the screen is 0.2°. The whole apparatus is immersed in water, then find out angular fringe width, (refractive index of water = $\frac{4}{3}$).

Solution

$$\alpha_{air} = \frac{\lambda}{d} \Rightarrow \alpha_{air} = 0.2° \Rightarrow \alpha \propto \lambda \Rightarrow \frac{\alpha_w}{\alpha_{air}} = \frac{\lambda_w}{\lambda_{air}} \Rightarrow \lambda_w = \frac{\lambda_{air}}{\mu} \Rightarrow \alpha_w = \frac{\alpha_{air}\,\lambda}{\mu.\lambda} = \frac{0.2 \times 3}{4} = 0.15°$$

Illustration 10

The path difference between two interfering waves at a point on screen is 171.5 times the wavelength. If the path difference is 0.01029 cm. Find the wavelength.

Solution

Path difference = $171.5\,\lambda = \frac{343}{2}\lambda$ = odd multiple of half wavelength . It means dark finge is observed

According to question $0.01029 = \frac{343}{2}\lambda \Rightarrow \lambda = \frac{0.01029 \times 2}{343} = 6 \times 10^{-5}\text{cm} \Rightarrow \lambda = 6000$ Å

Illustration 11

In young's double slit interference experiment, the distance between two sources is $0.1/\pi$ mm. The distance of the screen from the source is 25 cm. Wavelength of light used is 5000Å. Then what is the angular position of the first dark fringe ?

Solution

The angular position $\theta = \frac{\beta}{D} = \frac{\lambda}{d}$ $(\because \ \beta = \frac{\lambda D}{d})$ The first dark fringe will be at half the fringe width from the mid point of central maximum. Thus the angular position of first dark fringe will be-

$$\alpha = \frac{\theta}{2} = \frac{1}{2}\left[\frac{\lambda}{d}\right] = \frac{1}{2}\left[\frac{5000\times\pi}{.1\times10^{-3}}\times10^{-10}\right]\frac{180}{\pi} = 0.45°.$$

BEGINNER'S BOX-2

1. In Young's double slit experiment, the slits are 2mm apart and are illuminated with a mixture of two wavelength, λ = 7500 Å and λ' = 9000 Å. At what minimum distance from the common central bright fringe on a screen 2 m from the slits will a bright fringe from one interference pattern coincide with a bright fringe from the other ?

2. In a Young's double slit experiment the angular width of fringe formed on a distant screen is 0·1 radian. Find the distance between the two slits if wavelength of light used is 6000Å.

3. Two slits in Youngs experiment are 0·02 cm apart. The interference fringes for light of wavelength 6000Å are formed on a screen 80cm away. Calculate the distance of the fifth bright fringe.

4. In Young's double slit experiment, two slits are separated by 3mm distance and illuminated by light of wavelength 480 nm. The screen is at 2m from the plane of the slits. Calculate the separation between the 8^{th} bright fringe and the 3^{rd} dark fringe obtained with respect to central Bright fringe.

5. In a double slit experiment with monochromatic light, fringes are obtained on a screen placed at some distance from slits. If the screen is moved by 5×10^{-2} m towards the slits, the change in fringe width is 3×10^{-5} m. If the distance between slits is 10^{-3} m. Calculate the wavelength of light used.

6. In young's experiment for interference of light the slits 0.2 cm apart are illuminated by yellow light (λ = 5896 Å). What would be the fringe width on a screen placed 1m from the plane of slits. What will be the fringe width if the system is immersed in water. (μ_w = 4/3) ?

7. The distance between the coherent source is 0.3 mm and the screen is 90 cm from the sources. The second dark band is 0.3 cm away from central bright fringe. Find the wavelength and the distance of the fourth bright fringe from central bright fringe.

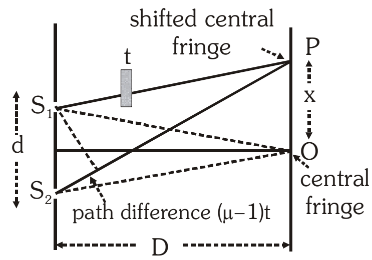
8. State two conditions to obtain sustained interference of light. In Young's double slit experiment, using light of wavelength 400 nm, interference fringes of width 'X' are obtained. The wavelength of light is increased to 600 nm and the separation between the slits is halved. If one wants the observed fringe width on the screen to be the same in the two cases, find the ratio of the distance between the screen and the plane of the slits in the two arrangements.

9. In a Young's double slit experiment, light has a frequency of 6×10^{14} Hz. The distance between the centres of adjacent bright fringes is 0.75 mm. If the screen is 1.5 m away then find the distance between the slits.

10. In a Young's experiment, the width of the fringes obtained with light of wavelength 6000 Å is 2.0 mm. What will be the fringe width, if the entire apparatus is immersed in a liquid of refractive index 1.33 ?

EFFECT OF THIN FILMS

When a glass plate of thickness t and refractive index μ is placed in front of one of the slits in YDSE then the central fringe shifts towards that side in which glass plate is placed because extra path difference is introduced by the glass plate. In the path S_1P distance travelled by wave in air = $(S_1P - t)$



Distance travelled by wave in the sheet = t

Time taken by light to reach up to point P will be same from S_1 and S_2

$$\frac{S_2P}{c} = \frac{S_1P - t}{c} + \frac{t}{c/\mu} \Rightarrow \frac{S_2P}{c} = \frac{S_1P + (\mu-1)t}{c} \Rightarrow S_2P = S_1P + (\mu-1)t \Rightarrow S_2P - S_1P = (\mu-1)t$$

Path difference = $(\mu-1)t$ $\Rightarrow$ Phase difference $\phi = \frac{2\pi}{\lambda}(\mu-1)t$; Number of fringes displaced = $\frac{(\mu-1)t}{\lambda}$

Distance of shifted fringe from central fringe $x = \frac{D(\mu-1)t}{d}$ $\left[\because \frac{xd}{D} = (\mu-1)t\right]$

$\therefore\ x = \frac{\beta(\mu-1)t}{\lambda}$ and $\beta = \frac{D\lambda}{d}$

COLOURS IN THIN FILMS

When white light is incident on a thin film (like oil film on the surface of water or a soap bubble) then interference takes place between the waves reflected from its two surfaces and waves refracted through it. The intensity becomes maximum and minimum as a result of interference and colours are seen.

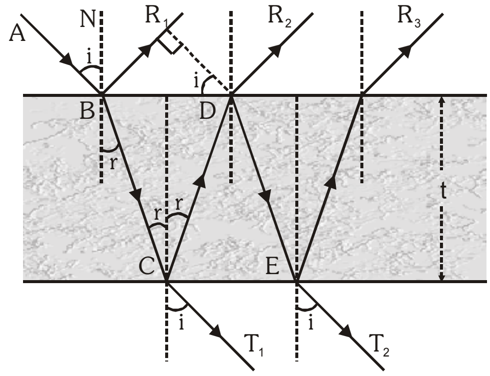
(i) The source of light must be an extended source.

(ii) The colours obtained in reflected and transmitted light are mutually complementary.

(iii) The colours obtained in thin films are due to interference whereas those obtained in prism are due to dispersion.

INTERFERENCE DUE TO THIN FILMS

Consider a thin transparent film of thickness t and refractive index μ. Let a ray of light AB be incident on the film at B. At B, a part of light is reflected along BR_1, and a part of light refracted along BC. At C a part of light is reflected along CD and a part of light transmitted along CT_1. At D, a part of light is refracted along DR_2 and a part of light is reflected along DE. Thus interference in this film takes place due to reflected light in between BR_1 and DR_2 also in transmitted light in between CT_1 and ET_2. Here coherent sources are obtained by division of amplitude.



- **Reflected System**

  The path difference between BR_1 and DR_2 is $x = 2\mu t \cos r$. Reflection from the surface of denser medium involves an additional phase difference of π or path difference $\lambda/2$. Therefore the effective path difference between BR_1 and DR_2 is. $\Rightarrow x' = 2\mu t \cos r - \lambda/2$

  Maximum or constructive Interference occurs when path difference between the light waves is $n\lambda$.

  $2\mu t \cos r - \lambda/2 = n\lambda \Rightarrow 2\mu t \cos r = n\lambda + \lambda/2$

  So the film will appear bright if $2\mu t \cos r = (2n + 1)\lambda/2$ $(n = 0, 1, 2, 3 \ldots..)$

- **For minima or destructive interference :**

  When path difference is odd multiple of $\frac{\lambda}{2} \Rightarrow 2\mu t \cos r - \frac{\lambda}{2} = (2n-1)\frac{\lambda}{2}$

  So the film will appear dark if $2\mu t \cos r = n\lambda$

- **For transmitted system**

  Since no additional path difference between transmitted rays CT_1 and ET_2.

  So the net path difference between them is $x = 2\mu t \cos r$

  For maxima $2\mu t\cos r = n\lambda$, $n = 0, 1, 2$............

  For minima $2\mu t\cos r = (2n+1)\frac{\lambda}{2}$, $n = 0, 1, 2$............

USES OF INTERFERENCE EFFECT

Thin layer of oil on water and soap bubbles show different colours due to interference of waves reflected from two surfaces of their films. Here we get two coherent beams by division of amplitude making use of partial reflection and partial refraction

Uses :

- Used to determine the wavelength of light precisely.
- Used to determine refractive index or thickness of transparent sheet.
- Used in holography to produce 3-D images.

GOLDEN KEY POINTS

- If a glass plate of refractive index μ_1 and μ_2 having same thickness t is placed in the path of rays coming from S_1 and S_2 then path difference $x = \frac{D}{d}(\mu_1 - \mu_2)t$
- Distance of displaced fringe from central fringe $x = \frac{\beta(\mu_1 - \mu_2)t}{\lambda}$ $\because \frac{\beta}{\lambda} = \frac{D}{d}$

Illustrations

Illustration 12

Light of wavelength 6000Å is incident on a thin glass plate of refractive index 1.5 such that angle of refraction into the plate is 60°. Calculate the smallest thickness of plate which will make it appear dark by reflection.

Solution

$$2\mu t \cos r = n\lambda$$

$$t = \frac{n\lambda}{2\mu \cos r} = \frac{1\times 6\times 10^{-7}}{2\times 1.5\times \cos 60}$$

$$= \frac{6\times 10^{-7}}{1.5} = 4\times 10^{-7}\,\text{m}$$

Illustration 13

Light is incident on a glass plate ($\mu = 1.5$) such that angle of refraction is 60°. Dark band is observed corresponding to the wavelength of 6000Å . If the thickness of glass plate is 1.2×10^{-3} mm. calculate the order of the interference band for reflected system.

Solution

$\mu = 1.5$, $r = 60°$, $\lambda = 6000\text{Å} = 6\times 10^{-7}\,\text{m}$

$t = 1.2\times 10^{-3}\,\text{mm} = 1.2\times 10^{-6}\,\text{m}$

For dark band in the reflected light $2\mu t \cos r = n\lambda$

$$n = \frac{2\mu t \cos r}{\lambda} = \frac{2\times 1.5\times 1.2\times 10^{-6}\times \cos 60^\circ}{6\times 10^{-7}}$$

$$= \frac{2\times 1.5\times 1.2\times 10^{-6}\times \frac{1}{2}}{6\times 10^{-7}} = 3$$

Thus third dark band is observed.

BEGINNER'S BOX-3

1. On placing a thin sheet of mica of thickness 12×10^{-7} m in the path of one of interferring beams in a Young's experiment, it is found that the central bright band shifts a distance equal to the width of a bright fringe. If the wavelength of light used is 6×10^{-7} m. then find refractive index of mica.

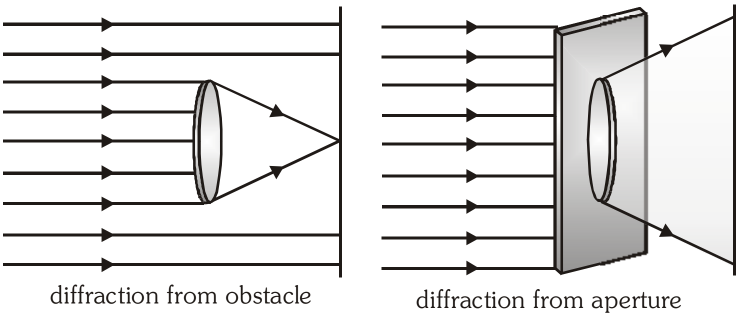
2. A central fringe of the interference produced by light of wavelength 6000Å is shifted to the position of 5th bright fringes by introducing a thin glass plate of refractive index 1.5. Calculate the thickness of the plate.

3. White light is incident on a soap film of refractive index $\frac{4}{3}$ at an angle of refraction 30°. The reflected light is observed to have a dark band for wavelength 6×10^{-5} cm. Calculate the minimum thickness of the film.

4. A soap solution film of $\mu = \frac{4}{3}$ is illuminated by white light incident with angle of refraction is 60°. In reflected light, dark band was found corresponding to wavelength 5500 Å. Calculate the minimum thickness of the film.

DIFFRACTION OF LIGHT

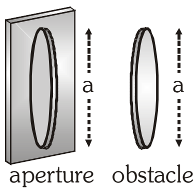
Bending of light rays from sharp edges of an opaque obstacle or aperture and its spreading in the geometrical shadow region is defined as diffraction of light or deviation of light from its rectilinear propogation tendency is defined as diffraction of light.

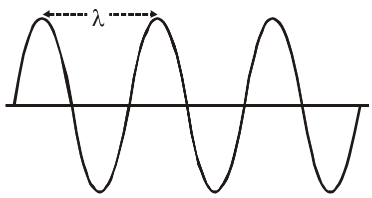


- Diffraction was discovered by Grimaldi.
- Theoretically explained by Fresnel
- Diffraction is possible in all type of waves means mechanical or electromagnetic waves shows diffraction.

Diffraction depends on two factors :

(i) Size of obstacles or aperture (ii) Wavelength of the wave



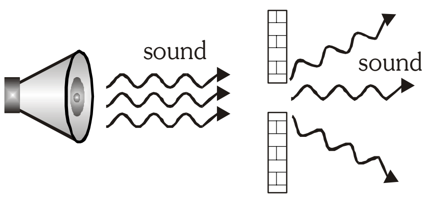


Condition of diffraction : Size of obstacle or aperture should be nearly equal to the wavelength of light

i.e. $\lambda \simeq a$ $\frac{a}{\lambda} \simeq 1$

If size of obstacle is much greater than wavelength of light, then rectilinear motion of light is observed.

- It is practically observed when size of aperture or obstacle is greater than 50 λ. The obstacle or aperature does not shows diffraction.
- Wavelength of light is of the order 10^{-7} m. In general obstacle of this wavelength is not present so light rays does not show diffraction and it appears to travel in straight line Sound wave shows more diffraction as compared to light rays because wavelength of sound is large (16 mm to 16m). So it is generally diffracted by the objects of our daily life.
- Diffraction of ultrasonic waves is also not observed easily because their wavelength is of the order of about 1 cm. Diffraction of radio waves is very conveniently observed because of its very large wavelength (2.5 m to 250 m). X-rays can be diffracted easily by crystals. It was discovered by Lave.



diffraction of sound from a window

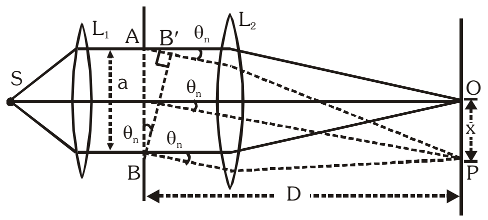
FRAUNHOFER DIFFRACTION

In fraunhofer diffraction both source and screen are effectively at infinite distance from the diffracting device and pattern is the image of source modified by diffraction effects.

Diffraction at single slit, double slit are the example of Fraunhofer diffraction.

FRAUNHOFER DIFFRACTION DUE TO SINGLE SLIT

AB is single slit of width a, Plane wavefront is incident on a slit AB. Secondary wavelets coming from every part of AB reach the axial point O in same phase forming the central maxima. The intensity of central maxima is maximum in this diffraction. where θ_n represents direction of n^{th} minima, Path difference AB' = a sin θ_n



for n^{th} minima $a\sin\theta_n = n\lambda$ $\quad\therefore\quad$ $\sin\theta_n \approx \theta_n = \dfrac{n\lambda}{a}$ (if θ_n is small)

- When path difference between the secondary wavelets coming from A and B is $n\lambda$ or $2n\left[\dfrac{\lambda}{2}\right]$ or even multiple of $\dfrac{\lambda}{2}$ then minima occurs

  For minima $a\sin\theta_n = 2n\left[\dfrac{\lambda}{2}\right]$ where n = 1, 2, 3 ...

- When path difference between the secondary wavelets coming from A and B is $(2n+1)\dfrac{\lambda}{2}$ or odd multiple of $\dfrac{\lambda}{2}$ then maxima occurs

  For maxima $\quad a\sin\theta_n = (2n + 1)\dfrac{\lambda}{2}$ $\quad$ where n = 1, 2, 3 ...

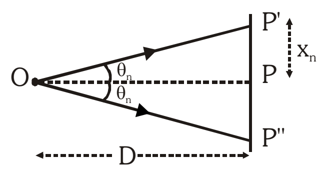
  n = 1 $\rightarrow$ first maxima and n = 2 $\rightarrow$ second maxima

- Alternate ordered minima and maxima occurs on both sides of central maxima.

  For n^{th} minima

  If distance of n^{th} minima from central maxima = x_n

  distance of slit from screen = D , width of slit = a



  Path difference $\delta = a\sin\theta_n = \dfrac{2n\lambda}{2} \Rightarrow \sin\theta_n = \dfrac{n\lambda}{a}$

  In Δ POP' $\tan\theta_n = \dfrac{x_n}{D}$ $\quad$ If θ_n is small $\Rightarrow \sin\theta_n \approx \tan\theta_n \approx \theta_n$

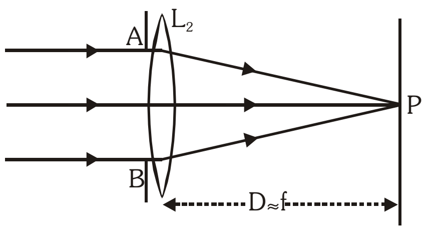
$x_n = \frac{n\lambda D}{a} \Rightarrow \theta_n = \frac{x_n}{D} = \frac{n\lambda}{a}$ First minima occurs on both sides of central maxima.

For first minima $x = \frac{D\lambda}{a}$ and $\theta = \frac{x}{D} = \frac{\lambda}{a}$

- Linear width of central maxima $w_x = 2x \Rightarrow w_x = \frac{2D\lambda}{a}$
- Angular width of central maxima $w_\theta = 2\theta = \frac{2\lambda}{a}$

SPECIAL CASE

Lens L_2 is shifted very near to slit AB. In this case distance between slit and screen will be nearly equal to the focal length of lens L_2 (i.e. $D \approx f$) $\theta_n = \frac{x_n}{f} = \frac{n\lambda}{a} \Rightarrow x_n = \frac{n\lambda f}{a}$

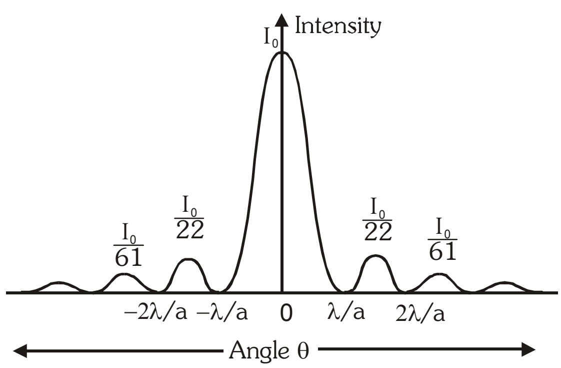


$w_x = \frac{2\lambda f}{a}$ and angular width of central maxima $w_\theta = \frac{2x}{f} = \frac{2\lambda}{a}$

Fringe width : Distance between two consecutive maxima (bright fringe) or minima (dark fringe) is known as fringe width. Fringe width of central maxima is doubled then the width of other maxima i.e.,

$$\beta = x_{n+1} - x_n = (n+1)\frac{\lambda D}{a} - \frac{n\lambda D}{a} = \frac{\lambda D}{a} \text{ (other than central maxima)}$$

Intensity curve of Fraunhofer's diffraction



DIFFERENCE BETWEEN INTERFERENCE AND DIFFRACTION (FOR FRAUNHOFER SINGLE SLIT) :

	Interference		Fraunhofer diffraction
(1)	It is the phenomenon of superposition of two waves coming from two different coherent sources.	(1)	It is the phenomenon of superposition of two waves coming from two different parts of the same wave front.
(2)	In interference pattern, all bright lines are equally bright and equally spaced.	(2)	All bright lines are not equally bright and equally wide. Brightness and width goes on decreasing with the angle of diffraction.
(3)	All dark lines are totally dark	(3)	Dark lines are perfectly dark. Their contrast with bright lines and width goes on decreasing with angle of diffraction.
(4)	In interference bands are large in number	(4)	In diffraction bands are few in number.

GOLDEN KEY POINTS

- The width of central maxima $\propto \lambda$, that is, more for red colour and less for blue.

  i.e., $w_x \propto \lambda$ as $\lambda_{blue} < \lambda_{red} \Rightarrow w_{blue} < w_{red}$

- For obtaining the fraunhofer diffraction, focal length of second lens (L_2) is used.

  $w_x \propto \lambda \propto f \propto 1/a$ width will be more for narrow slit

- By decreasing linear width of slit, the width of central maxima increase.
- The angular width of a beam of light of wavelength λ on account of diffraction at a slit of width a is given by

  $$\theta = \frac{\lambda}{a}$$

  If this beam is allowed to travel a distance Z,

  linear width acquired by the beam = $Z\theta = \frac{Z\lambda}{a}$

  Let Z_F be that value of Z for which the width of the beam becomes equal to a, i.e.,

  $$\frac{Z_F\lambda}{a} = a \quad \text{or} \quad Z_F = \frac{a^2}{\lambda}$$

Z_F is called the Fresnel distance.

Illustrations

Illustration 14

Light of wavelength 6000Å is incident normally on a slit of width 24×10^{-5} cm. Find out the angular position of second minimum from central maximum ?

Solution

$a \sin\theta = 2\lambda$ given $\lambda = 6 \times 10^{-7}$ m, $a = 24 \times 10^{-5} \times 10^{-2}$ m

$$\sin\theta = \frac{2\lambda}{a} = \frac{2 \times 6 \times 10^{-7}}{24 \times 10^{-7}} = \frac{1}{2} \qquad \therefore \quad \theta = 30°$$

Illustration 15

Light of wavelength 6328Å is incident normally on a slit of width 0.2 mm. Calculate the angular width of central maximum on a screen distance 9 m ?

Solution

given $\lambda = 6.328 \times 10^{-7}$ m, a = 0.2×10^{-3} m

$$w_\theta = \frac{2\lambda}{a} = \frac{2\times6.328\times10^{-7}}{2\times10^{-4}} \text{radian} = \frac{6.328\times10^{-3}\times180}{3.14} = 0.36°$$

Illustration 16

Light of wavelength 5000Å is incident on a slit of width 0.1 mm. Find out the width of the central bright line on a screen distance 2m from the slit ?

Solution

$$w_x = \frac{2f\lambda}{a} = \frac{2\times2\times5\times10^{-7}}{10^{-4}} = 20 \text{ mm}$$

Illustration 17

The Fraunhofer diffraction pattern of a single slit is formed at the focal plane of a lens of focal length 1m. The width of the slit is 0.3 mm. If the third minimum is formed at a distance of 5 mm from the central maximum then calculate the wavelength of light.

Solution

$$x_n = \frac{nf\lambda}{a} \Rightarrow \qquad \lambda = \frac{ax_n}{fn} = \frac{3\times10^{-4}\times5\times10^{-3}}{3\times1} = 5000 \text{ Å} \qquad [\because\ n = 3]$$

Illustration 18

Find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width 12×10^{-5} cm when the slit is illuminated by monochromatic light of wavelength 6000 Å.

Solution

$\because \qquad \sin\theta = \frac{\lambda}{a} \qquad\qquad \theta$ = half angular width of the central maximum.

a = 12×10^{-5} cm, λ = 6000 Å = 6×10^{-5} cm $\qquad \therefore \qquad \sin\theta = \frac{\lambda}{a} = \frac{6\times10^{-5}}{12\times10^{-5}} = 0.50 \qquad \Rightarrow \theta = 30°$

Illustration 19

Light of wavelength 6000 Å is incident on a slit of width 0.30 mm. The screen is placed 2 m from the slit. Find (a) the position of the first dark fringe and (b) the width of the central bright fringe.

Solution

The first fringe is on either side of the central bright fringe.

here $\qquad n = \pm1$, D = 2 m, λ = 6000 Å = 6×10^{-7} m

$\therefore \qquad \sin\theta = \frac{x}{D} \qquad \Rightarrow a = 0.30 \text{ mm} = 3 \times 10^{-4} \text{ m} \Rightarrow a\sin\theta = n\lambda \Rightarrow \frac{ax}{D} = n\lambda$

(a) $\qquad x = \frac{n\lambda D}{a} \qquad \Rightarrow x = \pm\left[\frac{1\times6\times10^{-7}\times2}{3\times10^{-4}}\right] = \pm4\times10^{-3}\text{m}$

The positive and negative signs corresponds to the dark fringes on either side of the central bright fringe.

(b) $\qquad$ The width of the central bright fringe y = 2x = $2 \times 4 \times 10^{-3} = 8 \times 10^{-3}$ m = 8 mm

Illustration 20

A Slit of width a is illuminated by monochromatic light of wavelength 650nm at normal incidence. Calculate the value of a when -

(a) the first minimum falls at an angle of diffraction of 30°

(b) the first maximum falls at an angle of diffraction of 30°.

Solution

(a) for first minimum $\sin\theta_1 = \frac{\lambda}{a}$ $\quad \therefore a = \frac{\lambda}{\sin\theta_1} = \frac{650\times10^{-9}}{\sin 30°} = \frac{650\times10^{-9}}{0.5} = 1.3 \times 10^{-6}$m

(b) For first maximum $\sin\theta_1 = \frac{3\lambda}{2a}$ $\quad \therefore a = \frac{3\lambda}{2\sin\theta} = \frac{3\times650\times10^{-9}}{2\times0.5} = 1.95 \times 10^{-6}$m

Illustration 21

Red light of wavelength 6500Å from a distant source falls on a slit 0.50 mm wide. What is the distance between the first two dark bands on each side of the central bright of the diffraction pattern observed on a screen placed 1.8 m. from the slit.

Solution

Given λ = 6500Å = 65 × 10^{-8} m, a = 0.5 mm = 0.5 × 10^{-3} m., D = 1.8 m.

Required distance between first two dark bands will be equal to width of central maxima.

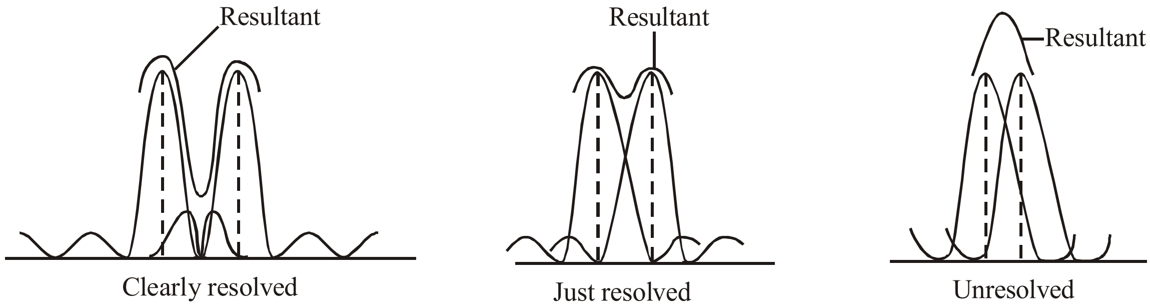
$$W_x = \frac{2\lambda D}{a} = \frac{2\times6500\times10^{-10}\times1.8}{0.5\times10^{-3}} = 468 \times 10^{-5} \text{ m} = 4.68 \text{ mm}$$

BEGINNER'S BOX-4

1. A slit of width 0·15 cm is illuminated by light of wavelength 5×10^{-5} cm and a diffraction pattern is obtained on a screen 2·1m away. Calculate the width of central maxima.
2. The light of wavelength 600nm is incident normally on a slit of width 3mm. Calculate the angular width of central maximum on a screen kept 3m away from the slit.
3. Red light of wavelength 6500Å from a distant source falls on a slit 0.50 mm wide. What is the distance between the first two dark bands on each side of the central bright of the diffraction pattern observed on a screen placed 1.8 m from the slit.
4. In a single slit diffraction experiment first minimum for λ_1 = 660 nm coincides with first maxima for wavelength λ_2. Calculate λ_2.

RAYLEIGH'S CRITERION FOR RESOLUTION

When a point source of light is imaged by an optical system with a circular aperture, the image is an Airy disc. If two points are very close, their Airy discs will overlap and we may not be able to resolve them, i.e., distinguish separate images.



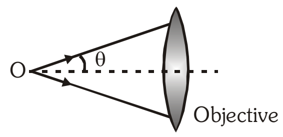
Two points are just resolved by an optical system when the central maximum of the diffraction pattern due to one falls on the first minimum of the diffraction pattern of the other.

RESOLVING POWER (R.P.)

A large number of images are formed as a consequence of light diffraction from a source. If two sources are separated such that their central maxima do not overlap, their images can be distinguished and are said to be resolved R.P. of an optical instrument is its ability to distinguish two neighbouring points.

(1) **Microscope :** In reference to a microscope, the minimum distance between two lines at which they are just distinct is called Resolving limit (RL) and it's reciprocal is called Resolving power (RP)

$$\text{R.L.} = \frac{1.22\lambda}{2\mu\sin\theta} \text{ and } \text{R.P.} = \frac{2\mu\sin\theta}{1.22\lambda} \Rightarrow \text{R.P.} \propto \frac{1}{\lambda}$$



λ = Wavelength of light used to illuminate the object

μ = Refractive index of the medium between object and objective,

θ = Half angle of the cone of light from the point object, $\mu\sin\theta$ = Numerical aperture.

(2) **Telescope :** Smallest angular separations ($d\theta$) between two distant object, whose images are separated in the telescope is called resolving limit. So resolving limit $d\theta = \frac{1.22\lambda}{a}$ and resolving power

$$(\text{RP}) = \frac{1}{d\theta} = \frac{a}{1.22\lambda} \Rightarrow \text{R.P.} \propto \frac{1}{\lambda}$$ where a = aperture of objective.

Illustrations

Illustration 22

The Hale telescope of Mount Palomar has a diameter of 200 inch. What is its limiting angle of resolution for 600 nm light?

Solution

Here; a = 200 in = 200 $\times$2.54 cm = 508 cm = 5.08 m

$\lambda = 600 \text{ nm} = 600 \times 10^{-9} \text{ m} = 6.00 \times 10^{-7} \text{ m}$

$$\Delta\theta = 1.22\left(\frac{\lambda}{a}\right) = 1.22\left(\frac{6.00\times10^{-7}\text{ m}}{5.08\text{m}}\right) = 1.44 \times 10^{-7} \text{ rad}$$

BEGINNER'S BOX-5

1. Calculate the resolving power of a telescope, assuming the diameter of the objective lens to be 6 cm and the wavelength of light used to be 540 nm.

2. Calculate the limit of resolution of a microscope if an object of numerical aperture 0.12 is viewed by using light of wavelength 6×10^{-7} m.

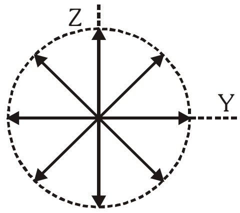
POLARISATION

Experiments on interference and diffraction have shown that light is a form of wave motion. These effects do not tell us about the type of wave motion i.e., whether the light waves are longitudinal or transverese.

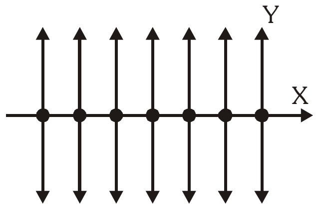
The phenomenon of polarization has helped to establish beyond doubt that light waves are transverse waves.

UNPOLARISED LIGHT

An ordinary beam of light consists of a large number of waves emitted by the atoms of the light source. Each atom produces a wave with its own orientation of electric vector $\vec{E}$ so all direction of vibration of $\vec{E}$ are equally probable.



unpolarised light
propagating along .
X-axis



unpolarised light

The resultant electromagnetic wave is a superposition of waves produced by the individual atomic sources and it is called unpolarised light. In ordinary or unpolarised light, the vibrations of the electric vector occur symmetrically in all possible directions in a plane perpendicular to the direction of propagation of light.

POLARISATION

The phenomenon of restricting the vibration of light (electric vector) in a particular direction perpendicular to the direction of propagation of wave is called polarisation of light. In polarised light, the vibration of the electric vector occur in a plane perpendicular to the direction of propagation of light and are confined to a single direction in the plane (do not occur symmetrically in all possible directions). After polarisation the vibrations become asymmetrical about the direction of propagation of light.

POLARISER

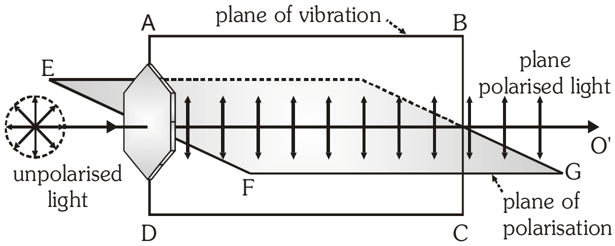
Tourmaline crystal : When light is passed through a tourmaline crystal cut parallel to its optic axis, the vibrations of the light carrying out of the tourmaline crystal are confined only to one direction in a plane perpendicular to the direction of propagation of light. The emergent light from the crystal is said to be plane polarised light.

Nicol Prism : A nicol prism is an optical device which can be used for the production and detection of plane polarised light. It was invented by William Nicol in 1828.

Polaroid : A polaroid is a thin commercial sheet in the form of circular disc which makes use of the property of selective absorption to produce an intense beam of plane polarised light.

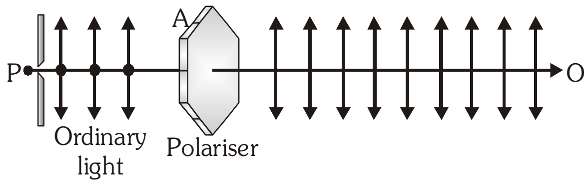
PLANE OF POLARISATION AND PLANE OF VIBRATION :

The plane in which vibrations of light vector and the direction of propogation lie is known as plane of vibration A plane normal to the plane of vibration and in which no vibration takes place is known as plane of polarisation



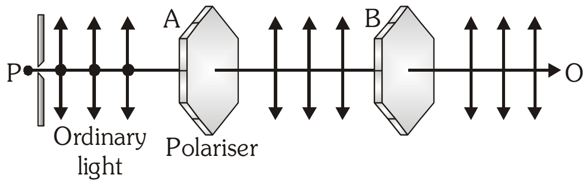
EXPERIMENTAL DEMONSTRATION OF POLARISATION OF LIGHT

Take two tourmaline crystals cut parallel to their crystallographic axis (optic axis).

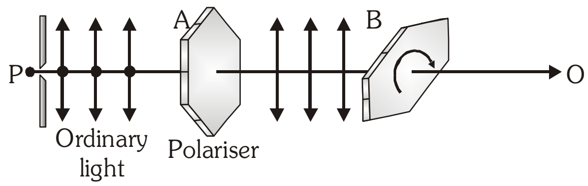


First hold the crystal A normally to the path of a beam of colour light. The emergent beam will be slightly coloured. Rotate the crystal A about PO. No change in the intensity or the colour of the emergent beam of light.

Take another crystal B and hold it in the path of the emergent beam of so that its axis is parallel to the axis of the crystal A. The beam of light passes through both the crystals and outcoming light appears coloured.



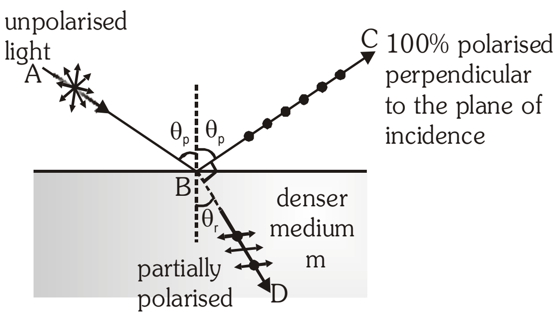
Now, rotate the crystal B about the axis PO. It will be seen that the intensity of the emergent beam decreases and when the axes of both the crystals are at right angles to each other no light comes out of the crystal B.



If the crystal B is further rotated light reappears and intensity becomes maximum again when their axis are parallel. This occurs after a further rotation of B through 90°. This experiment confirms that the light waves are transverse in nature. The vibrations in light waves are perpendicular to the direction of propogation of the the wave. First crystal A polarises the light so it is called polariser. Second crystal B, analyses the light whether it is polarised or not, so it is called analyser.

METHODS OF OBTAINING PLANE POLARISED LIGHT

- **Polarisation by reflection** : The simplest method to produce plane polarised light is by reflection. This method was discovered by Malus in 1808. When a beam of ordinary light is reflected from a surface, the reflected light is partially polarised. (The degree of polarisation of the polarised light in the reflected beam is greatest when it is incident at an angle called polarising angle or Brewster's angle).



- **Polarising angle** : Polarising angle is that angle of incidence at which the reflected light is completely plane polarisation.
- **Brewster's Law** : When unpolarised light strikes at polarising angle θ_P on an interface separating a rare medium from a denser medium of refractive index μ , such that $\mu = \tan\theta_P$ then the reflected light (light in rare medium) is completely polarised. Also reflected and refracted rays are normal to each other. This relation is known as Brewster's law. The law state that the tan function of the polarising angle of incidence of a transparent medium is equal to its refractive index $\mu = \tan\theta_P$

In case of polarisation by reflection :

(i) For $i = \theta_P$ refracted light is partially polarised.

(ii) For $i = \theta_P$ reflected and refracted rays are perpendicular to each other.

(iii) For $i < \theta_P$ or $i > \theta_P$ both reflected and refracted light become partially polarised.

According to snell's law $\mu = \dfrac{\sin\theta_p}{\sin\theta_r}$ ...(i)

But according to Brewster's law $\mu = \tan\theta_p = \dfrac{\sin\theta_p}{\cos\theta_p}$ ...(ii)

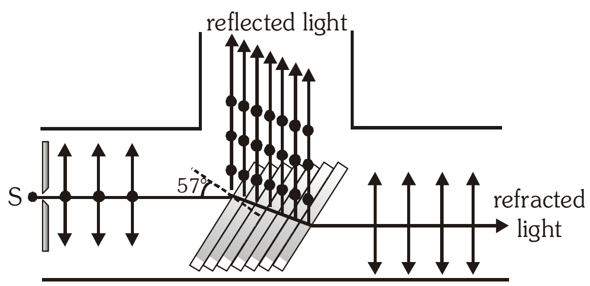
From equation (i) and (ii) $\dfrac{\sin\theta_p}{\sin\theta_r} = \dfrac{\sin\theta_p}{\cos\theta_p} \Rightarrow \sin\theta_r = \cos\theta_p$

$\therefore \sin\theta_r = \sin(90° - \theta_p) \Rightarrow \theta_r = 90° - \theta_p$ or $\theta_p + \theta_r = 90°$

Thus reflected and refracted rays are mutually perpendicular

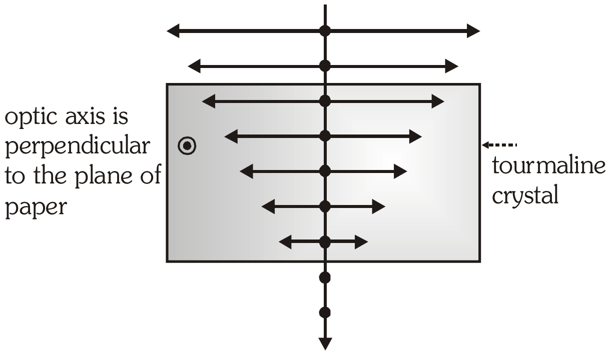
By Refraction

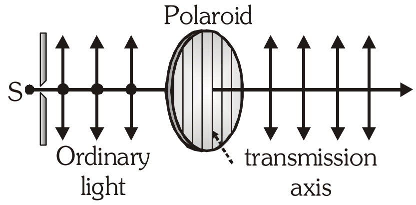
In this method, a pile of glass plates is formed by taking 20 to 30 microscope slides and light is made to be incident at polarising angle 57°. According Brewster's law, the reflected light will be plane polarised with vibrations perpendicular to the plane of incidence and the transmitted light will be partially polarised. Since in one reflection about 15% of the light with vibration perpendicular to plane of paper is reflected therefore after passing through a number of plates emerging light will become plane polarised with vibrations in the plane of paper.



By Dichroism

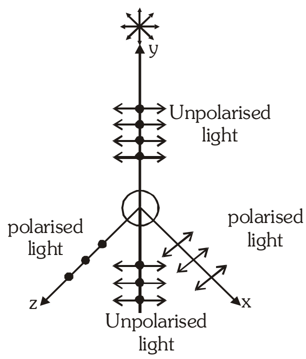
Some crystals such as tourmaline and sheets of iodosulphate of quinone have the property of strongly absorbing the light with vibrations perpendicular of a specific direction (called transmision axis) and transmitting the light with vibration parallel to it. This selective absorption of light is called dichroism. So if unpolarised light passes through proper thickness of these crystals, the transmitted light will plane polarised with vibrations parallel to transmission axis. Polaroids work on this principle.





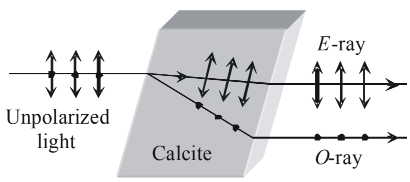
By scattering :

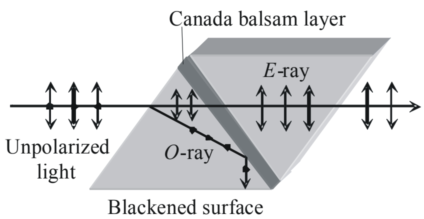
When light is incident on small particles of dust, air molecules etc. s(having smaller size as compared to the wavelength of light), it is absorbed by the electrons and is re-radiated in all directions. The phenomenon is called as scattering. Light scattered in a direction at right angles to the incident light is always plane-polarised.



By Double Refraction :

It was found that in certain crystals such as calcite, quartz and tourmaline, etc., incident unpolarised light splits in into two light beams of equal intensities with perpendicular polarisations. One of the rays behaves as ordinary light and is called O-ray (ordinary ray) while the other does not obey laws of refraction and is called E-ray (extra-ordinary ray). This is why when an object is seen through these crystal is rotated, one image (due to E-ray) rotates around the other (due to O-ray).



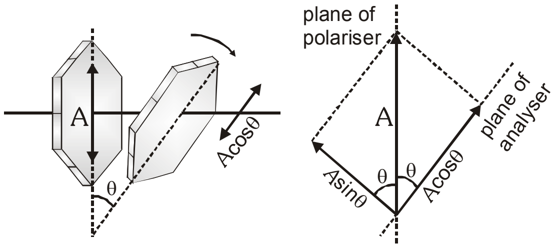


By using the phenomenon of double refraction and isolating one ray from the other we can obtain plane polarised light which actually happens in a Nicol-prism. Nicol-prism is made up of calcite crystal and in it E-ray is isolated from O-ray through total internal reflection of O-ray at canada balsam layer and then absorbing it at the blackened surface as shown in figure.

Law of Malus

- When a completely plane polarised light beam is incident on analyser, then intensity of emergent light varies as the square of cosine of the angle between the planes of transmission axis of the analyser and the polarizer.

$I \propto \cos^2\theta \Rightarrow I = I_0 \cos^2\theta$



(i) If $\theta = 0°$ then $I = I_0$ maximum value (Parallel arrangement)

(ii) If $\theta = 90°$ then $I = 0$ minimum value (Crossed arrangement)

- If plane polarised light of intensity $I_0(= KA^2)$ is incident on a polaroid and its vibrations of amplitude A make angle θ with transmission axis, then the component of vibrations parallel to transmission axis will be $A\cos\theta$ while perpendicular to it will be $A\sin\theta$.

Polaroid will pass only those vibrations which are parallel to transmission axis i.e. $A\cos\theta$, $\because I_0 \propto A^2$

So the intensity of emergent light $I = K(A\cos\theta)^2 = KA^2\cos^2\theta$

- If an unpolarised light is converted into plane polarised light its intensity becomes half.
- If light of intensity I_1, emerging from one polaroid called polariser is incident on a second polaroid (called analyser) the intensity of light emerging from the second polaroid is

$I_2 = I_1 \cos^2\theta$ θ = angle between the transmission axis of the two polaroids.

GOLDEN KEY POINTS

- Our eyes are nearly insensitive to polarisation of light, but this is not universally true for animals.
- If the angle of incidence is 0° or 90° the reflected beam is unpolarised.
- A Nicol prism is made by cutting a calcite crystal in a certain way.

Illustrations

Illustration 23

For a given medium, the polarising angle is 60° . What will be the critical angle for this medium?

Solution

Here $i_p = 60°$

Thus, $\mu = \tan i_p = \tan 60° = \sqrt{3}$

If i_c is the critical angle for the medium.

$\mu = \frac{1}{\sin i_c}$ or $\sin i_c = \frac{1}{\mu} = \frac{1}{\sqrt{3}}$ or $\sin i_c = 0.5774$ or $i_c = 35°16'$

Illustration 24

A ray of light is incident on the surface of glass plate of refracive index 1.5 at polarising angle. What is the angle of refraction?

Solution

As $\mu = \tan i_p$, $\tan i_p = 1.5$ or $i_p = \tan^{-1}(1.5)$ or $i_p = 56°19'$

As $r + i_p = 90°$, $r = 90° - i_p = 33°41'$

BEGINNER'S BOX-6

1. Refractive index of water is 1.33. Calculate the angle of polarisation for light reflected from the surface of a lake. ($\tan^{-1} 1.33 = 53°.4'$)

2. A ray of light strikes a glass plate at an angle of 60°. If the reflected and the refracted rays are perpendicular to each other, find the index of refraction of glass.

3. A parallel beam of light is incident at an angle of 60° on a plane glass surface and the reflected beam is completely polarised.

(a) What is the angle of refraction in glass?

(b) What is the refraction index of glass?

4. Light reflected from the surface of a glass plate of refractive index 1.732 is linearly polarised. Calculate the angle of refraction in glass.

5. Critical angle for a certain wavelength of light in case of glass is 40°. Find the polarising angle and angle of refraction in glass corresponding to this. ($\sin 40° = \frac{2}{3}$)

ANSWERS

BEGINNER'S BOX-1

1. 5I **2.** $\frac{25}{16}$

3. (a) 7.8I (b) I (c) 9I

BEGINNER'S BOX-2

1. 4.5 mm **2.** 6μm

3. 1·2 cm **4.** 1.76×10^{-3} m

5. 6×10^{-7} m

6. 0.2948 mm, 0.2211 mm

7. 8×10^{-3} m, $\lambda = 0.66 \times 10^{-6}$ m

8. $\frac{3}{1}$ **9.** 10^{-3} m. **10.** 1.5 mm

BEGINNER'S BOX-3

1. 1·5 **2.** 6×10^{-6} m

3. 2.59×10^{-5} cm **4.** 4125 Å

BEGINNER'S BOX-4

1. 1·4 mm **2.** 0.023°

3. 4.68 mm **4.** 440 nm.

BEGINNER'S BOX-5

1. 9.1×10^{4} **2.** 3.05×10^{-6} m.

BEGINNER'S BOX-6

1. 53°4' **2.** 1.732

3. (a) 30° (b) 1.732 **4.** 30°

5. 57.3°, 32.7°

EXERCISE-I (Conceptual Questions)

HUYGEN'S WAVE THEORY OF LIGHT

1. Which of the following phenomenon can not be explained by the Huygen's theory -

(1) Refraction

(2) Reflection

(3) Diffraction

(4) Polarization

2. Huygen's principle is applicable to -

(1) Only light waves

(2) Only sound waves

(3) Only mechanical waves

(4) For all the above waves

3. According to huygen's theory of secondary wavelets, following can be explained -

(1) Propagation of light in medium

(2) Reflection of light

(3) Refraction of light

(4) All of the above

4. Huygen's theory of secondary waves can be used to find-

(1) Velocity of light

(2) The wavelength of light

(3) Wave front geometrically

(4) Magnifying power of microscope

5. The main drawback of huygen's theory was-

(1) Failure in explanation of rectilinear propagation of lignt

(2) Failure of explain the spectrum of white light

(3) Failure to explain the formation of newton's rings

(4) A failure of experimental verification of ether medium

6. Light has a wave nature, because-

(1) the light travel in a straight line

(2) Light exhibits phenomenon of reflection and refraction

(3) Light exhibits phenomenon of interference

(4) Light exhibits phenomenon of photo electric effect

7. Wave nature of light is verified by-

(1) Interference (2) Photo electric effect

(3) Reflection (4) Refraction

INTERFERENCE

8. The energy in the phenomenon of interference :

(1) is conserved, gets redistributed

(2) is equal at every point

(3) is destroyed in regions of dark fringes

(4) is created at the place of bright fringes

9. The resultant amplitude in interference with two coherent sources depends upon :

(1) only amplitude (2) only phase difference

(3) on both the above (4) none of the above

10. Which of following nature of light waves is supported by the phenomenon of interference :

(1) longitudinal

(2) transverse

(3) both transverse and longitudinal

(4) None of the above

11. For distinct interference pattern to be observed, necessary condition is that ratio of intensity of light emission by both the sources should be :

(1) 2 : 1 (2) 1 : 2

(3) 1 : 1 (4) 1 : 4

12. The phase difference corresponding to path difference of x is :

(1) $\frac{2\pi x}{\lambda}$ (2) $\frac{2\pi\lambda}{x}$ (3) $\frac{\pi x}{\lambda}$ (4) $\frac{\pi\lambda}{x}$

13. The coherent source of light produces constructive interference when phase difference betwen them is :

(1) π (2) $\frac{1}{2}\pi$ (3) $\frac{3}{2}\pi$ (4) 2π

14. Phenomenon of interference is not observed by two sodium lamps of same power. It is because both waves have :

(1) not constant phase difference

(2) zero phase difference

(3) different intensity

(4) different frequencies

15. Coherent sources can be obtained :

(1) only by division of wave front

(2) only by division of amplitude

(3) both by division of amplitude and wave front

(4) none of the above

16. In an interference of light derived from two slit apertures, if at some point on the screen, yellow light has a path difference of $\frac{3\lambda}{2}$, then the fringe at that point will be :

(1) yellow in colour (2) white in colour

(3) dark (4) bright

17. Two beams of light having intensities I and 4I interfer to produce a fringe pattern on a screen. The phase difference between the beam is $\frac{\pi}{2}$ at point A and 2π at point B. Then find out the difference between the resultant intensities at A and B.

(1) 2I (2) 5I (3) I (4) 4I

18. Amplitude of waves observed by two light sources of same wave length are a and 2a and have a phase difference of π between them. Then minimum intensity of light will be proportional to :

(1) 0 (2) $5a^2$ (3) a^2 (4) $9a^2$

19. If the intensity of the waves observed by two coherent sources is I. Then the intensity of resultant wave in constructive interference will be :

(1) 2I (2) 4I

(3) I (4) None of the above

20. If intensity of each of the two waves is I and they are having phase difference of 120^0, when the waves are superimposed, then the resultant intensity will be :

(1) I (2) 2I (3) I/2 (4) 4I

21. Ratio of intensity of two waves is 25 : 1. If interference occurs, then ratio of maximum and minimum intensity should be :

(1) 25 : 1 (2) 5 : 1 (3) 9 : 4 (4) 4 : 9

22. The intensity of two waves is 2 and 3 unit, then average intensity of light in the overlapping region will have the value :

(1) 2.5 (2) 6 (3) 5 (4) 13

23 The light waves from two independent monochromatic light sources are given by –

$y_1 = 2\sin(\omega t - kx)$ and $y_2 = 3\cos(\omega t - kx)$,

then the following statement is correct

(1) Both the waves are coherent

(2) Both the waves are incoherent

(3) Both the waves have different time periods

(4) None of the above

24. The phenomenon of interference is shown by :

(1) Longitudinal mechanical waves only

(2) Transverse mechanical waves only

(3) Electromagnetic waves only

(4) All the above type of waves

25. For the sustained interference of light, the necessary condition is that the two sources should :

(1) Have constant phase difference

(2) Be narrow

(3) Be close to each other

(4) Of same amplitude

26. If ratio of amplitude of two interfering source is 3 : 5. Then ratio of intensity of maxima and minima in interference pattern will be :

(1) 25 : 16 (2) 5 : 3 (3) 16 : 1 (4) 25 : 9

27. Two coherent light beams of intensity I and 4I are superposed. The maximum and minimum possible intensities in the resulting beam are :

(1) 5I and 3I (2) 5I and I

(3) 9I and 3I (4) 9I and I

28. Two coherent sources of intensities I_1 and I_2 produce an interference pattern. The maximum intensity in the interference pattern will be :

(1) $I_1 + I_2$ (2) $I_1^2 + I_2^2$

(3) $(I_1 + I_2)^2$ (4) $\left(\sqrt{I_1} + \sqrt{I_2}\right)^2$

29. Two wave are represented by the equations y_1 = a sin ωt and y_2 = a cos ωt.The first wave :

(1) Leads the second by π

(2) Lags the second by π

(3) Leads the second by $\frac{\pi}{2}$

(4) Lags the second by $\frac{\pi}{2}$

30. The resultant amplitude of a vibrating particle by the superposition of the two waves $y_1 = a\sin\left(\omega t + \frac{\pi}{3}\right)$ and $y_2 = a \sin \omega t$ is :-

(1) a (2) $\sqrt{2}$ a (3) 2a (4) $\sqrt{3}$ a

31. Two coherent sources of different intensities send waves which interfere. If the ratio of maximum and minimum intensity in the interference pattern is 25 then find ratio of intensities of sources :

(1) 25 : 1 (2) 5 : 1 (3) 9 : 4 (4) 25 : 16

32. What is the path difference of destructive interference :

(1) nλ (2) n(λ + 1)

(3) $\frac{(n+1)\lambda}{2}$ (4) $\frac{(2n+1)\lambda}{2}$

33. If an interference pattern have maximum and minimum intensities in 36 :1 ratio then what will be the ratio of amplitudes :

(1) 5 : 7 (2) 7 : 4 (3) 4 : 7 (4) 7 : 5

34. When a thin transparent plate of thickness t and refractive index μ is placed in the path of one of the two interfering waves of light, then the path difference changes by :

(1) (μ + 1)t (2) (μ – 1)t

(3) $\frac{(\mu+1)}{t}$ (4) $\frac{(\mu-1)}{t}$

35. Due to effect of interfernce, floating oil layer in water is visible coloured, due to observation of this event the thickness of oil layer should be :

(1) 10 nm (2) 0.1 μm (3) 1 mm (4) 10 mm

36. If intensity ratio of two interfering waves is 9 : 1 then ratio of maximum to minimum amplitude of resultant wave is :

(1) 2 : 1 (2) 3 : 2 (3) 1 : 3 (4) 5 : 2

37. For coherent sources which is essential :-

(1) colour same (2) φ constant

(3) ν different (4) Amplitude same

38. When exposed to sunlight, thin films of oil on water often exhibit brilliant colors due to the phenomenon of –

(1) interference (2) diffraction

(3) dispersion (4) polarisation

39. If $\frac{I_1}{I_2} = \frac{9}{1}$ then $\frac{I_{max}}{I_{min}} = ?$

(1) 100 : 64 (2) 64 : 100

(3) 4 : 1 (4) 1 : 4

40. Soap bubble appears coloured due to the phenomenon of :-

(1) Total internal reflection

(2) Interference by division of amplitude

(3) Interference by division of wavefront

(4) Diffraction of light

41. Two coherent light sources emit light of the

(1) same intensity

(2) different frequency

(3) constant phase difference but different wavelengths

(4) same frequency having constant phase difference

YDSE

42. In Young's experiment, if the amplitude of interferring waves are unequal then the :

(1) contrast in the fringes decreases

(2) contrast in the fringes increase

(3) number of fringes will increase

(4) number of fringes will decrease

43. Young's experiment proves that which of the following fact :

(1) light is made up of particles

(2) light is made up of waves

(3) light is made up of neither waves nor particles

(4) fringe width doesn't depend upon the spacing between slits.

44. Which of the following statement is true, in Young's experiment, separation between the slits is gradually increased :

(1) fringe width increases and fringes disappear

(2) fringe width decreases and fringes disappear

(3) fringes become blurred

(4) fringe width remains constant and fringes are more bright

45. In Young's double slit experiment :

(1) only interference occurs

(2) only diffraction occurs

(3) both interference and diffraction occurs

(4) none of the above

46. In Young's double slit experiment, one of the slits is so painted that intensity of light emitted from it is half of that of the light emitted from other slit. Then:

(1) fringe system will disappear

(2) bright fringes will become brighter and dark fringes will be darker

(3) both bright and dark fringes will become darker

(4) dark fringes will become less dark and bright fringes will become less bright.

47. In white light interference, nearest to the central (bright) fringe, will have which of the following colour

(1) violet (2) yellow

(3) red (4) green

48. In Young's double slit experiment, wavelength of light is 6000Å. Then the phase difference between the light waves reaching the third bright fringe from the central fringe will be :

(1) zero (2) 2π

(3) 4π (4) 6π

49. If intensity of each wave in the observed interference pattern in Young's double slit experiment is I_0. then for some point P where the phase difference is ϕ, intensity I will be :

(1) $I = I_0 \cos\phi$

(2) $I = I_0 \cos^2 \phi$

(3) $I = I_0 (1+\cos\phi)$

(4) $I = 2I_0(1+\cos\phi)$

50. In Young's double slit experiment, bright fringes are of :

(1) equal widths and unequal intensities

(2) unequal widths and equal intensities

(3) equal widths and equal intensities

(4) unequal widths and unequal intensities

51. In Young's experiment, monochromatic light through a single slit S is used to illuminate the two slits S_1 and S_2. Interference fringes are obtained on a screen. The fringe width is found to be w. Now a thin sheet of mica (thickness t and refractive index μ) is placed near and in front of one of the two slits. Now the fringe width is found to be w′, then :

(1) $w' = w/\mu$ (2) $w' = w\mu$

(3) $w' = (\mu - 1)\,tw$ (4) $w' = w$

52. In Young's double slit experiment, the two slits act as coherent sources of equal amplitude A and wavelength λ. In another experiment with the same set up the two slits are sources of equal amplitude A and wavelength λ but are incoherent. The ratio of the intensity of light at the mid-point of the screen in the first case to that in the second case is :

(1) 4 : 1 (2) 2 : 1

(3) 1 : 1 (4) None of the above

53. In Young's double slit experiment, if the width of the slits are in the ratio 4 : 9 the ratio of the intensity of maxima to the intensity at minima will be :

(1) 169 : 25 (2) 81 : 16

(3) 25 : 1 (4) 9 : 4

54. In an interference experiment, the spacing between successive maxima or minima is :

(1) $\frac{\lambda d}{D}$ (2) $\frac{\lambda D}{d}$

(3) $\frac{dD}{\lambda}$ (4) $\frac{\lambda d}{4D}$

55. Young's experiment is performed in air and then performed in water, the fringe width :

(1) Will remain same (2) Will decrease

(3) Will increase (4) Will be infinite

56. In Young's experiment, one slit is covered with a blue filter and the other with a yellow filter. Then the interference pattern :

(1) Will be blue (2) Will be yellow

(3) Will be green (4) Will not be formed

57. In Young's double slit experiment, a mica sheet of thickness t and refractive index μ is introduced in the path of ray from the first source S_1. By how much distance the fringe pattern will be displaced :

(1) $\frac{d}{D}(\mu - 1)t$ (2) $\frac{D}{d}(\mu - 1)t$

(3) $\frac{d}{(\mu - 1)D}$ (4) $\frac{D}{d}(\mu - 1)$

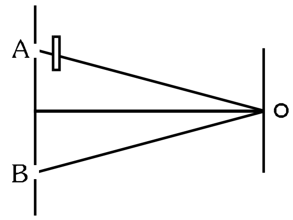
58. In Young's experiment, light of wavelength 6000Å is used to produce fringes of width 0.8 mm at a distance of 2.5 m. If the whole experiment is deep in a liquid of refractive index 1.6, then fringe width will be :

(1) 0.5 mm (2) 0.6 mm (3) 0.4 mm (4) 0.2 mm

59. If a transparent medium of refractive index $\mu = 1.5$ and thickness $t = 2.5 \times 10^{-5}$ m is inserted in front of the slits of Young's Double slit experiment, how much will be the shift in the interference pattern? The distance between the slits is 0.5 mm and that between slits and screen is 100 cm :

(1) 5 cm (2) 2.5 cm (3) 0.25 cm (4) 0.1 cm

60. In Young's experiment, monochromatic light is used to illuminate the two slits A and B. Interference fringes are observed on a screen placed in front of the slits.



Now if a thin glass plate is placed normally in the path of the beam coming from the slit then :

(1) The fringes will disappear

(2) The fringe width will decrease

(3) The fringe width will increase

(4) There will be no change in the fringe width

61. The central fringe of interference pattern produced by light of wavelength 6000Å is found to shift to the position of 4th bright fringe, after a glass plate of $\mu = 1.5$ is introduced. The thickness of the glass plate is :

(1) 4.8 μm (2) 8.23 μm

(3) 14.98 μm (4) 3.78 μm

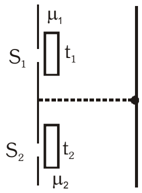
62. In a Young's double slit experiment, a slab of thickness 1.2 μm and refractive index 1.5 is placed in front of one slit and another slab of thickness t and refractive index 2.5 is placed in front of the second slit. If the position of the central fringe remains unaltered, then the thickness t is–

(1) 0.4 μm

(2) 0.8 μm

(3) 1.2 μm

(4) 7 μm



63. In Y.D.S.E. the fringe width is 0.2 mm. If wavelength of light is increase by 10% and separation between the slits is increased by 10% then fringe width will be :

(1) 0.20 mm (2) 0.165 mm

(3) 0.401 mm (4) 0.242 mm

64. A very thin transparent film of soap solution (thickness $\rightarrow$ 0) is seen under reflection of white light. Then the colour of the film appear to be :

(1) blue (2) black

(3) red (4) yellow

65. In Young's double slit experiment, if monochromatic light is replaced by white light :

(1) All bright fringes become white

(2) All bright fringes have coloures between violet and red

(3) Only the central fringe is white, all other fringes are coloured

(4) No fringes are observed

66. The fringe width in Young's double slit experiment increases when :

(1) Wavelength increases

(2) Distance between the slits increases

(3) Distance between the source and screen decreases

(4) Frequency of incident light increases

67. Young's double slit experiment is performed with light of wavelength 550 nm. The separation between the slits is 1.10 mm and screen is placed at distance of 1m. What is the distance between the consecutive bright or dark fringes.

(1) 1.5 mm (2) 1.0 mm

(3) 0.5 mm (4) None of these

68. In the Young's double slit experiment, for which colour the fringe width is least ?

(1) Red (2) Green

(3) Blue (4) Yellow

69. If the sodium light in Young's double slit experiment is replaced by red light, the fringe width will :

(1) Decrease

(2) Increase

(3) Remain unaffected

(4) First increase, then decrease

70. A double slit experiment is performed with light of wavelength 500 nm. A thin film of thickness 2μm and refractive index 1.5 is introduced in the path of the upper beam. The location of the central maximum will :

(1) Remain unshifted

(2) Shift downward by nearly two fringes

(3) Shift upward by nearly two fringes

(4) Shift downward by 10 fringes

71. In YDSE experiment, when two light waves make third minima, then they have :-

(1) Phase difference of 3π

(2) Phase difference of $\frac{5\pi}{2}$

(3) Path difference of 3λ

(4) Path difference of $\frac{5\lambda}{2}$

72. If in a Young's double slit experiment, width between the slits is 3 cm, the separation between slits and screen is 7 cm and wavelength of light is 1000 Å, then fringe width will be

(1) 2×10^{-5} m. (2) 2×10^{-9} m

(3) 0.2×10^{-6} m (4) 2.3×10^{-7} m

73. A monochromatic beam of light is used for the formation of fringes on the screen by illuminating the two slits in the Young's double slit interference experiment. When a thin film of mica is interposed in the path of one of the interfering beams then :

(1) The fringe width increases

(2) The fringe width decreases

(3) The fringe width remains the same but the pattern shifts

(4) The fringe pattern disappears

74. In an interference experiment, third bright fringe is obtained at a point on the screen with a light of 700 nm. What should be the wavelength of the light in order to obtain 5^{th} bright fringe at the same point ?

(1) 500 nm (2) 630 nm

(3) 750 nm (4) 420 nm

75. In a double slit experiment if light of wavelength 5000 Å is used then fringe width of 1 mm is obtained. If now light of wavelength 6000 Å is used without altering the system then new fringe width will be :

(1) 1 mm (2) 0·5 mm

(3) 1·2 mm (4) 1·5 mm

76. Monochromatic green light has wavelength 5×10^{-7} m. The separation between slits is 1 mm. The fringe width of interference patern obtained on screen at a distance of 2 meter is :

(1) 1 mm (2) 0.5 mm

(3) 2 mm (4) 0.1 mm

77. In Young's double slit experiment when wavelength of 700 nm is used then fringe width of 0.7 mm is obtained. If wavelength of 500nm is used then what is the fringe width?

(1) 0.35 mm (2) 0.5 mm

(3) 3.5 mm (4) 5 mm

78. What will be the effect on fringe width, when distance between slits become doubled-

(1) 1/2 times (2) 2 times

(3) 1/4 times (4) Unchanged

DIFFRACTION

79. The conversation going on, in some room, can be heared by the person outside the room. The reason for it is :

(1) Interference of sound (2) Reflection of sound

(3) Diffraction of sound (4) Refraction of sound

80. Phenomenon of diffraction occurs :

(1) only in case of light and sound waves

(2) for all kinds of waves

(3) for electro-magnetic waves and not for matter waves

(4) for light waves but not is case of X rays

81. Which of the following ray gives more distinct diffraction :

(1) X-ray (2) light ray

(3) γ –ray (4) Radio wave

82. All fringes of diffraction are of :

(1) the same intensity

(2) unequal width

(3) the same width

(4) full darkness

83. What happens, when the width of the slit aperture is increased in an experiment of single slit diffraction experiment :

(1) spread of diffraction region is increased

(2) spread of diffraction region is decreased

(3) spread of diffraction region will be decreased and mid-band becomes narrow

(4) none of the above

84. Light waves do not travels strictly in straight line, can be best explained by :

(1) Particle nature of light (2) Diffraction

(3) Interference (4) Polarisation

85. In the diffraction pattern of a single slit aperture, the width of the central fringe compared to widths of the other fringes, is :

(1) equal (2) less

(3) little more (4) double

86. Diffracted fringes obtained from the slit aperture are of :-

(1) same width

(2) different width

(3) uniform intensity

(4) non-uniform width & non uniform intensity

87. Central fringe obtained in diffraction pattern due to a single slit :

(1) is of minimum intensity

(2) is of maximum intensity

(3) intensity does not depend upon slit width

(4) none of the above

88. In a single slit diffraction pattern, if the light source is used of less wave length then previous one. Then width of the central fringe will be :

(1) less (2) increase

(3) unchanged (4) none of the above

89. In the laboratory, diffraction of light by a single slit is being observed. If slit is made slightly narrow, then diffraction pattern will :

(1) be more spreaded than before

(2) be less spreaded than before

(3) be spreaded as before

(4) be disappeared

90. For Fraunhofer single slit diffraction :

(1) width of central maxima is proportional to λ

(2) on increasing the slit width, the width of central maxima decreases

(3) on making the slit width $a = \lambda$, central fringe spreads in the range $\pm 90^0$

(4) all of the above are correct

91. In a Fraunhofer's diffraction by a slit, if slit width is a, wave length λ, focal length of lens is f, linear width of central maxima is :

(1) $\frac{f\lambda}{a}$ (2) $\frac{fa}{\lambda}$ (3) $\frac{2f\lambda}{a}$ (4) $\frac{f\lambda}{2a}$

92. In a Fraunhofer's diffraction obtained by a single slit aperture, the value of path difference for n^{th} order of minima is :

(1) $n\lambda$ (2) $2n\lambda$

(3) $(2n-1)\lambda/2$ (4) $(2n-1)\lambda$

93. A light source of 5000Å wave length produces a single slit diffraction. The first minima in diffraction pattern is seen, at a distance of 5mm from central maxima. The distance between screen and slit is 2 metre. The width of slit in mm will be :

(1) 0.1 (2) 0.4 (3) 0.2 (4) 2

94. A plane wave front of wave length 6000 Å is incident upon a slit of 0.2mm width, which enables Fraunhofer's diffraction pattern to be obtained on a screen 2 metre away. Width of the central maxima in mm will be :

(1) 10 (2) 12 (3) 8 (4) 2

95. The waves of 600μm wave length are incident normally on a slit of 1.2mm width. The value of diffraction angle corresponding to the first minima will be (in radian) :

(1) $\frac{\pi}{2}$ (2) $\frac{\pi}{6}$

(3) $\frac{\pi}{3}$ (4) $\frac{\pi}{4}$

96. In Fraunhoffer diffraction the centre of diffraction image is :

(1) always bright

(2) always dark

(3) sometimes bright and sometimes dark

(4) bright for large wavelength and dark for low wavelength

97. A single slit of width d is placed in the path of beam of wavelength λ. The angular width of the principal maximum obtained is :

(1) $\frac{d}{\lambda}$ (2) $\frac{\lambda}{d}$

(3) $\frac{2\lambda}{d}$ (4) $\frac{2d}{\lambda}$

98. Bending of light waves at the sharp edges of an opaque obstacle is known as

(1) refraction (2) reflection

(3) diffraction (4) interference

99. Diffraction and interference of light refers to :

(1) quantum nature of light

(2) wave nature of light

(3) transverse nature of light

(4) electromagnetic nature of light

100. The phenomenon of diffraction of light was discovered by :

(1) Huygens (2) Newton

(3) Fresnel (4) Grimaldi

101. Angular width (θ) of central maximum of a diffraction pattern of a single slit does not depend upon :

(1) Distance between slit and source

(2) Wavelength of light used

(3) Width of the slit

(4) Frequency of light used

102. Red light is generally used to observe diffraction pattern from single slit. If green light is used instead of red light, then diffraction pattern :

(1) Will be more clear

(2) Will be contract

(3) Will be expanded

(4) Will not visualize

103. Diffraction of sound waves is more evident than light waves in daily life because :-

(1) $\lambda_{Sound} > \lambda_{light}$

(2) $\lambda_{sound} = \lambda_{light}$

(3) $\lambda_{sound} < \lambda_{light}$

(4) Sound waves are longitudinal but light waves are transverse.

104. In single slit Fraunhoffer diffraction which type of wavefront is required :

(1) cylindrical (2) spherical

(3) elliptical (4) plane

105. If in Fraunhofer diffraction due to a single slit, the slit width is increased, then the width of the central maximum will

(1) increase

(2) decrease

(3) not change

(4) change depends on the wavelength of light used

POLARISATION, BREWSTER LAW AND MALUS LAW

106. A polariser is used to :

(1) Reduce intensity of light

(2) Produce polarised light

(3) Increase intensity of light

(4) Produce unpolarised light

107. Light waves can be polarised as they are :

(1) Transverse (2) Of high frequency

(3) Longitudinal (4) Reflected

108. Through which character we can distinguish the light waves from sound waves :

(1) Interference (2) Refraction

(3) Polarisation (4) Reflection

109. Which of following can not be polarised :

(1) Radio waves (2) Ultraviolet rays

(3) Infrared rays (4) Ultrasonic waves

110. The transverse nature of light is shown by

(1) Interference of light (2) Refraction of light

(3) Polarisation of light (4) Dispersion of light

111. The angle of polarisation for any medium is 60°, what will be critical angle for this :

(1) $\sin^{-1}\sqrt{3}$ (2) $\tan^{-1}\sqrt{3}$

(3) $\cos^{-1}\sqrt{3}$ (4) $\sin^{-1}\frac{1}{\sqrt{3}}$

112. The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refractive index n)

(1) $\sin^{-1}(n)$ (2) $\sin^{-1}\left(\frac{1}{n}\right)$

(3) $\tan^{-1}\left(\frac{1}{n}\right)$ (4) $\tan^{-1}(n)$

113. A ray of light is incident on the surface of a glass plate at an angle of incidence equal to Brewster's angle ϕ. If μ represents the refractive index of glass with respect to air, then the angle between reflected and refracted rays is :

(1) $90 + \phi$

(2) $\sin^{-1}(\mu\cos\phi)$

(3) 90°

(4) $90° - \sin^{-1}(\sin\phi/\mu)$

114. Refractive index of material is equal to tangent of polarizing angle. It is called.

(1) Brewster's law (2) Lambert's law

(3) Malus's law (4) Bragg's law

115. When unpolarized light beam is incident from air onto glass (n=1.5) at the polarizing angle :

(1) Reflected beam is 100 percent polarized

(2) Reflected and refracted beams are partially polarized

(3) The reflected and refracted ray will not perpendicular to each other

(4) All of the above

116. When the angle of incidence on a material is 60°, the reflected light is completely polarized. The velocity of the refracted ray inside the material is (in ms^{-1}) :

(1) 3×10^8 (2) $\left(\frac{3}{\sqrt{2}}\right) \times 10^8$

(3) $\sqrt{3} \times 10^8$ (4) 0.5×10^8

117. A polaroid is placed at 45° to an incoming light of intensity I_0. Now the intensity of light passing through polaroid after polarisation would be:

(1) I_0 (2) $I_0/2$

(3) $I_0/4$ (4) Zero

118. Plane polarised light is passed through a polaroid. On viewing through the polariod we find that when the polariod is given one complete rotation about the direction of the light, one of the following is observed.

(1) The intensity of light gradually decreases to zero and remains at zero

(2) The intensity of light gradually increases to a maximum and remains at maximum

(3) There is no change in intensity

(4) The intensity of light is twice maximum and twice zero

119. Polarised glass is used in sun glasses because :

(1) It reduces the light intensity to half an account of polarisation

(2) It is fashionable

(3) It has good colour

(4) It is cheaper

120. When a plane polarised light is passed through an analyser and analyser is rotated from 0 to 90°, the intensity of the emerging light :

(1) Varies between a maximum and minimum

(2) Becomes zero

(3) Does not vary

(4) Varies between a maximum and zero

121. When an unpolarized light of intensity I_0 is incident on a polarizing sheet, the intensity of the light which does not get transmitted is :

(1) Zero (2) I_0

(3) $\frac{1}{2}I_0$ (4) $\frac{1}{4}I_0$

EXERCISE-I (Conceptual Questions) ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans.	**4**	**4**	**4**	**3**	**4**	**3**	**1**	**1**	**3**	**4**	**3**	**1**	**4**	**1**	**3**
Que.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Ans.	**3**	**4**	**3**	**2**	**1**	**3**	**3**	**2**	**4**	**1**	**3**	**4**	**4**	**4**	**4**
Que.	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Ans.	**3**	**4**	**4**	**2**	**2**	**1**	**2**	**1**	**3**	**2**	**4**	**1**	**2**	**2**	**3**
Que.	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	**4**	**3**	**4**	**4**	**3**	**4**	**2**	**3**	**2**	**2**	**4**	**2**	**1**	**2**	**4**
Que.	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Ans.	**1**	**1**	**1**	**2**	**3**	**1**	**3**	**3**	**2**	**3**	**4**	**4**	**3**	**4**	**3**
Que.	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Ans.	**1**	**2**	**1**	**3**	**2**	**4**	**2**	**3**	**2**	**4**	**4**	**2**	**1**	**1**	**4**
Que.	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
Ans.	**3**	**1**	**3**	**2**	**2**	**1**	**3**	**3**	**2**	**4**	**1**	**2**	**1**	**4**	**2**
Que.	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
Ans.	**2**	**1**	**3**	**4**	**3**	**4**	**4**	**3**	**1**	**1**	**3**	**2**	**4**	**1**	**4**
Que.	121														
Ans.	**3**														

EXERCISE-II (Assertion & Reason)

Directions for Assertion & Reason questions

These questions consist of two statements each, printed as Assertion and Reason. While answering these Questions you are required to choose any one of the following four responses.

(A) If both Assertion & Reason are True & the Reason is a correct explanation of the Assertion.

(B) If both Assertion & Reason are True but Reason is not a correct explanation of the Assertion.

(C) If Assertion is True but the Reason is False.

(D) If both Assertion & Reason are false.

1. ***Assertion :*** If white light is used in YDSE, then the central bright fringe will be white

Reason : Because all the wavelengths produce their zero order maxima at the same position

(1) A (2) B (3) C (4) D

2. ***Assertion :*** In YDSE, if a thin film is introduced in front of the upper slit, then the fringe pattern shifts in the downward direction

Reason : In YDSE if the slit widths are unequal, the minima will be completely dark

(1) A (2) B (3) C (4) D

3. ***Assertion :–*** In YDSE interference pattern disappears when one of the slits is closed.

Reason :– Interference occurs due to super-imposition of light wave from two coherent sources.

(1) A (2) B (3) C (4) D

4. ***Assertion :*** Diffraction of sound waves are more easily observed as compare to light waves.

Reason : Wavelength of sound waves is more as compare to light.

(1) A (2) B (3) C (4) D

5. ***Assertion :*** If a person wants to observe sharp and clear frings of good contrast then interference experiment is prefrable compare to diffraction.

Reason : In diffraction intensity after the central maxima decreases rapidly, so fringe pattern become blurred.

(1) A (2) B (3) C (4) D

6. ***Assertion :*** Sharp edge of a fine needle doesn't cast clear shadow.

Reason : Sharp edge of needle will not produce observable diffraction for radio waves.

(1) A (2) B (3) C (4) D

7. ***Assertion :-*** When light ray is incident at polarising angle on glass, reflected light is partially polarised.

Reason :- The intensity of light decreases in polarisation.

(1) A (2) B (3) C (4) D

8. ***Assertion*** : The resolving power of a telescope is more if the diameter of the objective lens is more.

Reason : Objective lens of large diameter collects more light. **[AIIMS 2005]**

(1) A (2) B (3) C (4) D

9. **Assertion :-** The focal length of objective lens in telescope is much more than that of eye piece.

Reason :- Telescope has high resolving power due to large focal length. **[AIIMS 2012]**

(1) A (2) B (3) C (4) D

10. ***Assertion :-*** Resolving power of a telescope depends only on wavelength.

Reason :- This is proportional to square of wavelength. **[AIIMS 2013]**

(1) A (2) B (3) C (4) D

11. ***Assertion :-*** Polaroid glasses reduce glare from road or water etc. **[AIIMS 2015]**

Reason :- Reflected waves are partially polarised

(1) A (2) B (3) C (4) D

12. ***Assertion :-*** In YDSE the fringe separation doesn't contain any information about intensity of individual source.

Reason :- Fringe width depends on wavelength of source. **[AIIMS 2016]**

(1) A (2) B (3) C (4) D

13. ***Assertion :-*** Electron microscope provides better resolution than optical microscope. **[AIIMS 2016]**

Reason :- Energy of electron can be easily varied.

(1) A (2) B (3) C (4) D

14. ***Assertion :-*** Light ray passing through water droplet is partially polarised. **[AIIMS 2017]**

Reason :- Water is a polar molecule.

(1) A (2) B (3) C (4) D

15. ***Assertion :-*** Phase change of π occurs when light beam strikes a interface separating two surface.

Reason :- All EM wave suffer phase change of π when it strikes a interface. **[AIIMS 2017]**

(1) A (2) B (3) C (4) D

EXERCISE-II (Assertion & Reason) ANSWER KEY

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans.	1	4	1	1	1	2	4	2	3	4	1	2	1	1	4